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Impacts of Wastewater Disposal Practices on the Ground Water of the North Carolina Barrier Islands

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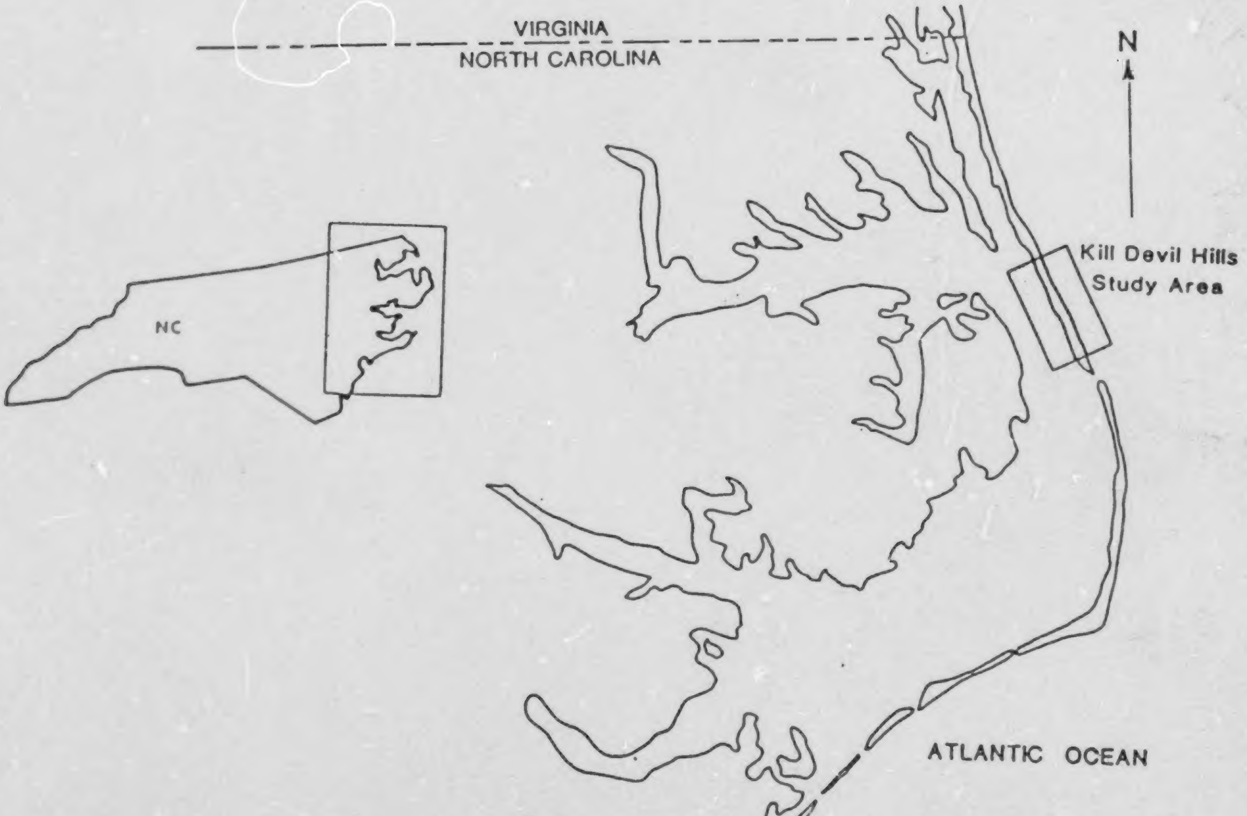
Final Report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NORTH CAROLINA
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Kill Devil Hills Study Area
ATLANTIC OCEAN
Atlantic Beach/Pine Knoll Shores Study Area
Surf City Study Area
Wilmington
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SUMMARY: EPA Region IV recently completed a study of the impacts of wastewater disposal on the ground water of three areas of the North Carolina barrier islands; Kill Devil Hills, Atlantic Beach/Pine Knoll Shores and Surf City. The study was performed in response to questions resulting from EPA Region IV's North Carolina Barrier Islands EIS (1984). The study demonstrated a simple model for describing the observed ground-water level changes caused by disposal of wastewater to the shallow aquifer system. The study also examined what were found to be the generally minor impacts of wastewater disposal on ground-water quality in the three study areas. The report contains all data, analyses and conclusions resulting from this study.

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The Impacts of Wastewater Disposal Practices on the Ground Water of the North Carolina Barrier Islands

FINAL REPORT
September, 1985

Prepared by
U.S. Environmental Protection Agency
Region IV, Atlanta, Georgia 30365

In January 1984, EPA published a Final Environmental Impact Statement (EIS) that identified the need for estimating the impacts of present wastewater treatment and disposal practices on the North Carolina barrier islands. The EIS identified increases in groundwater levels associated with the addition of wastewater to the water table and changes in groundwater quality as two areas of impact having the greatest significance.

This study examines these impacts for three areas of the North Carolina barrier islands; Kill Devil Hills, Atlantic Beach/Pine Knoll Shores and Surf City. The study has two primary objectives. One objective is to develop a simple model for computing groundwater level changes caused by disposal of wastewater to the shallow aquifer system. The second objective is to estimate the impact of the wastewater disposal on groundwater quality. Field work for the study was conducted July 1984 through May 1985.

The study determined that the disposal of wastewater had a minor impact on the water quality of the shallow aquifers at Kill Devil Hills and Surf City. Wastewater disposal had some impact on shallow groundwater quality in the Atlantic Beach/Pine Knoll Shores study area. The study also showed that wastewater disposal had resulted in increased groundwater levels in each of the study areas. The simple model was used to predict these water level impacts.

This report contains all data, analyses and conclusions resulting from this study. Comments or inquires should be forwarded to Robert B. Howard, Chief, NEPA Compliance Section, U.S. EPA - Region IV, 345 Courtland Street, N.E., Atlanta, Georgia 30365 (404) 881-3776.

Jack E. Ravan
Jack E. Ravan
Regional Administrator

SEP 20 1985
Date

THE IMPACTS OF WASTEWATER DISPOSAL PRACTICES ON THE GROUND WATER OF THE NORTH CAROLINA BARRIER ISLANDS

Prepared by

U.S. ENVIRONMENTAL PROTECTION AGENCY, REGION IV
ATLANTA, GEORGIA

With Assistance from

APPLIED BIOLOGY, INC.
DECATUR, GEORGIA

SEPTEMBER 1985

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North Carolina Department of Natural Resources and Community Development
Town of Kill Devil Hills
Town of Atlantic Beach
Town of Pine Knoll Shores
Town of Surf City

Inquiries regarding information in this handbook should be made to U.S. Environmental Protection Agency, Region IV, Environmental Assessment Branch, 345 Courtland Street, Atlanta, Georgia, 30365.

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EXECUTIVE SUMMARY

A critical factor to the continued population growth on the barrier islands along the coast of North Carolina is the impacts of wastewater disposal on ground-water levels and ground-water quality. Residents on the islands generally receive their water supply from the mainland or from deep wells on the islands. On-site systems are used to treat and dispose of the wastewater. This process results in a net addition of water to the shallowest aquifer underlying the islands.

Monitoring wells were constructed in the communities of Kill Devil Hills, Atlantic Beach, Pine Knoll Shores and Surf City to aid in defining the shallow subsurface hydrogeology of the barrier islands and to estimate the impacts of wastewater disposal on ground-water levels and water quality. Wells were completed along transects that were generally perpendicular to the ocean beach and extended across the width of the islands. The transect locations were chosen to reflect variations in population density. Hydrogeologic data obtained from the wells included lithologic data collected during drilling of the wells plus water level and water quality data collected during periodic visits to the islands.

Shallow subsurface conditions are similar in each of the areas studied. The shallow aquifer consists of fine to medium sands with interbedded silty sands that are underlain by beds of silt and clay. The silt and clay beds restrict the downward movement of water and in this sense promote the lateral movement of water toward the ocean and sound.

Ground-water movement in the shallow aquifer is generally away from the central part of the islands in each study area. Average flow velocities along transects varied from less than 0.1 to about 1.6 feet per day. Travel times from the center of the islands to discharge points along the ocean and sound, which are dependent upon the half-width of the island and the flow velocity, varied from as little as one year at Atlantic Beach to possibly decades at Pine Knoll Shores.

Accretion of water to the shallow aquifer in each study area comes from precipitation and wastewater disposal. Precipitation accounted for 86 percent or more of the water gain, or recharge, received along transects in Kill Devil Hills and Pine Knoll Shores, 70 percent of the recharge received along transects in Atlantic Beach, and 78 percent or more of the recharge received along Transects in Surf City during the study period. Wastewater disposal accounted for the remainder of the recharge received along the transects.

Water-table elevations in the Kill Devil Hills and Atlantic Beach/Pine Knoll Shores study areas varied similarly in response to recharge and discharge. Water levels would rise rapidly in response to precipitation and fall gradually at other times due to evapotranspiration and seepage of water to the ocean and sound. The observed long-term water-level recession rate due to natural discharge is about 0.03 feet per day in both areas. The influence of tidal fluctuations on water levels appears to be confined to areas adjacent to the ocean and sound.

Water-table elevations in the Surf City area were influenced by tidal fluctuations as well as by precipitation and discharge. Water levels rose and fell twice daily in response to tidal fluctuations. These fluctuations were superimposed upon broader fluctuations that varied with recharge and discharge. Water levels would rise rapidly in response to precipitation and fall gradually at other times due to natural discharge. The observed long-term water-level recession rate due to natural discharge is about 0.06 ft/day.

The shallow aquifers at Kill Devil Hills, Atlantic Beach and Pine Knoll Shores generally contained freshwater. Minor intrusions of brackish water were observed near the ocean at Transects K1 and K2 in Kill Devil Hills. Some brackish water was noted at Transect P2 in Pine Knoll Shores near the ocean and near Bogue Sound. In Atlantic Beach, brackish water generally existed in the confining beds underlying the shallow aquifer.

The shallow aquifer at Surf City contains a lens of freshwater underlain by brackish to saline water. This freshwater lens probably extends to a maximum depth of about 10 feet, which occurs at the center of the island.

The disposal of wastewater has had a minor impact on water quality in the shallow aquifers at Kill Devil Hills and Surf City. Nitrate/nitrite were detected in ground-water samples but never exceeded drinking water standards. MBAS levels above secondary drinking water standards were noted in only one ground-water sample from Kill Devil Hills and in none from Surf City. Fecal coliform were noted in two of 100 water samples taken from wells in Kill Devil Hills and in 10 of 61 water samples taken from wells in Surf City. Eight of the 10 water samples from Surf City with fecal coliform present were either one or two col/100 ml. The fecal coliform generally occurred in the summer or fall of 1984.

Wastewater disposal has had some impact on water quality in the shallow aquifer in the Atlantic Beach/Pine Knoll Shores study area. Extreme variations in fecal coliform were noted in water from some well sites. Intrusion of surface runoff into the wells at those sites is believed to be responsible for the fecal coliform in the wells. However, fecal coliform were also noted in water from some of the other well sites in the study area. These were generally detected in July 1984 and not detected at other times, although a few exceptions can be noted. Nitrate/nitrite and MBAS, although detected in water samples, did not exceed drinking water standards.

Wastewater disposal has resulted in increased water levels in each of the study areas. The largest increase, approximately one foot, has occurred at Atlantic Beach. The least impact, between 0.1 and 0.4 feet, has occurred at Pine Knoll Shores. A simple analytical model that was identified as a part of this study was used to compute these impacts.

There is no apparent correlation between the amount of wastewater disposal and the distribution of wastewater contaminants in the ground water except for fecal coliform bacteria.

1.0 INTRODUCTION

The barrier islands are a narrow chain of islands along the coast of North Carolina. These islands have a total length of approximately 260 miles. Island widths are typically 2,000 feet, but vary from less than 500 feet to more than two miles. Altitudes range from sea level to greater than 100 feet but are generally less than 20 feet.

Three areas on these islands have been studied. The first area is Kill Devil Hills on Bodie Island. The second area includes Atlantic Beach and Pine Knoll Shores on Bogue Banks. The third area is Surf City, on Topsail Island. The study area locations are shown in Figure 1-1.

Residents in the study areas generally receive their water supply from the mainland or from deep wells on the islands. Water is distributed to individual homes through municipal water supply distribution systems.

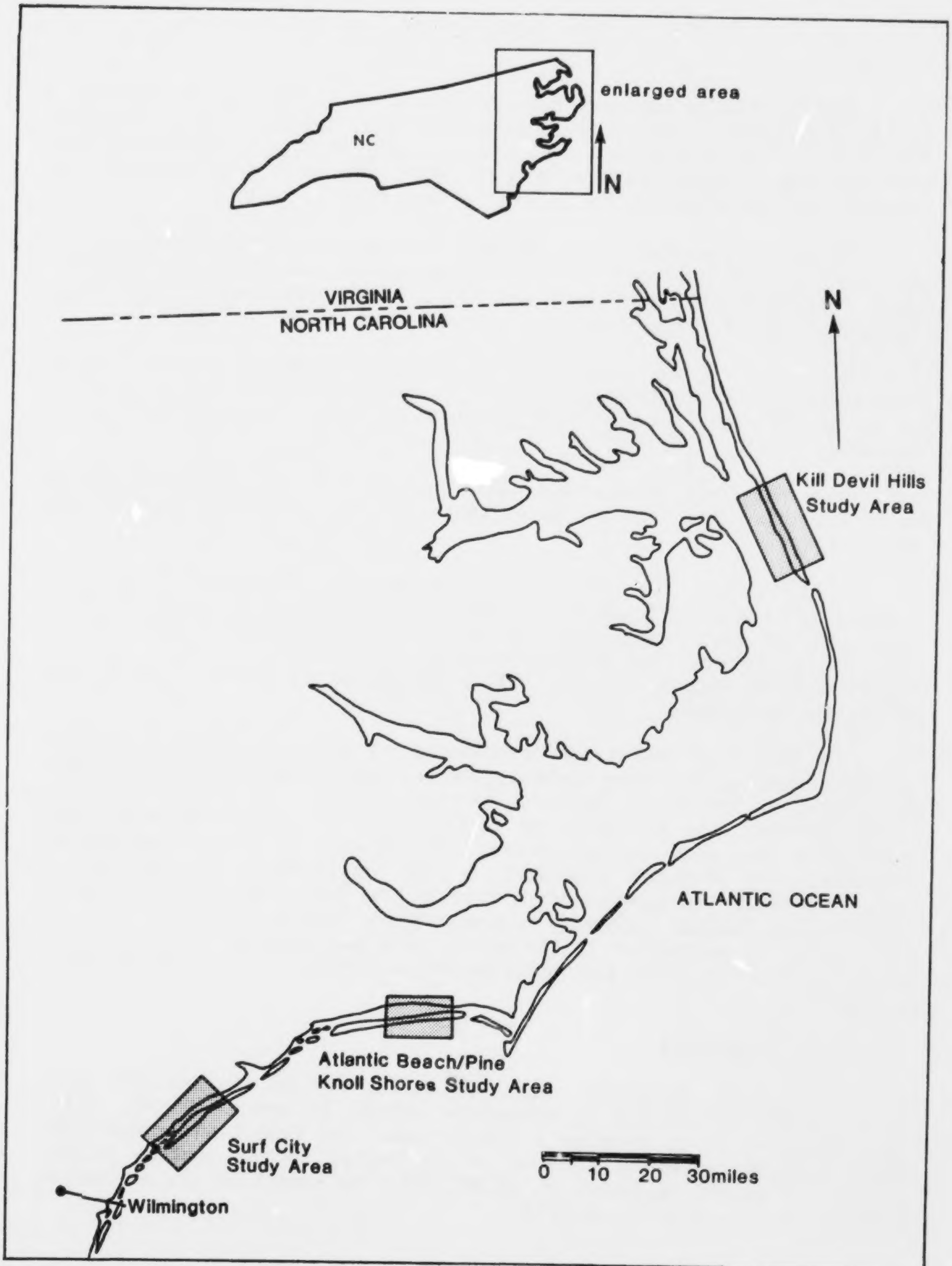
Some residents obtain their water supply from shallow wells. These wells withdraw water from the water table aquifer that directly underlies the islands.

All residents on the islands use on-site systems to treat and dispose of their wastewater. These systems generally consist of a package plant treatment system for multi-resident buildings and individual septic systems for private residences. A drain field is used in either case to dispose of the treated wastewater by infiltration of the water into the ground.

The U.S. Environmental Protection Agency (EPA) is actively involved in investigating alternate technologies that may be applied to wastewater management on the North Carolina barrier islands. As a part of these investigations, the EPA prepared an Environmental Impact Statement that identified the need for estimating the impacts of present wastewater treatment and disposal practices on the environment of the islands (USEPA, 1983). The impacts identified by the EPA as having the greatest significance include increases in ground-water levels associated with the percolation of wastewater to the water table and changes in ground-water quality resulting from the addition of wastewater to the ground-water system.

1.1 Study Objectives

This study addresses those objectives defined in the EPA North Carolina Barrier Islands Environmental Impact Statement (USEPA, 1983). One objective is to develop a simple model for computing ground-water level changes caused by disposal of wastewater to the shallow aquifer system. A second objective is to estimate the impact of the wastewater disposal on ground-water quality.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Atlantic Beach/Pine Knoll Shores Study Area
Surf City Study Area
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Wilmington

Figure 1-1. Location map.

1.2 Approach

Monitoring wells were constructed in each of the study areas along transects that were generally perpendicular to the ocean beach. Each transect extended across the width of the island. The transect locations in each study area were chosen to reflect variations in population density.

Hydrogeologic data were collected from the wells along each transect during the course of the study. The boreholes that were drilled for the wells were used to collect lithologic data to aid in defining the near-surface geology underlying each study area. Water-level data were collected periodically to aid in defining the relation between lithology and ground-water levels and to aid in estimating the impact of wastewater dipsosal on water levels. Water samples for chemical analyses were collected periodically to aid in defining the impact of wastewater disposal on water quality.

2.0 HYDROLOGIC FIELD DATA COLLECTION PROGRAM

The hydrologic field data collection program included installing monitoring wells and tidal gauges, conducting aquifer pumping tests and periodically collecting water level data and water samples for chemical analyses. These data were collected to aid in determining a hydrologic budget for each study area, to define the hydrogeology underlying each study area and to estimate the impacts of current wastewater disposal practices on the hydrogeology of the study areas.

Land and water use data were collected for each transect to aid in estimating wastewater disposal along the transects.

2.1 Installation of Monitoring Wells

One hundred temporary monitoring wells were constructed in the three study areas. Forty-one wells were constructed in the Kill Devil Hills study area, 42 in the Atlantic Beach/Pine Knoll Shores study area, and 17 in the Surf City study area.

2.1.1 Transect Locations

The wells in each study area were located along transect lines that extended across the width of the island. Transect lines were chosen to reflect variations in population density.

Tentative transect locations were identified during reconnaissance visits to the study areas. High population density, medium population density and low population density transects were identified, with the terms high, medium and low based on a visual impression of the relative degree of development along the transects. Transect locations were finalized through discussions with local officials.

Three transect lines were located in the Kill Devil Hills study area (Figures 2-1 and 2-2). One line, Transect K1, was located along Chowan Avenue in an area with a medium population density. A second line, Transect K2, was located along Fifth Avenue in an area with a high population density. A third line, Transect K3, was located immediately south of the Kitty Hawk Memorial in an area of relatively low population.

Four transect lines were located in the Atlantic Beach/Pine Knoll Shores study area. One line, Transect A1, was located along Dunes Avenue in Atlantic Beach. A second line, Transect A2, was located along Brooks Street and Wilson Avenue in Atlantic Beach. Both of these transects are in areas of high population density. A third line, Transect P1, was located along Yaupon Road in Pine Knoll Shores in an area with a medium population density. A fourth line, Transect P2, was located along Pine Knoll Boulevard in Pine Knoll Shores in an area with a low population density. The locations of the transects in Atlantic Beach and Pine Knoll Shores are shown in Figures 2-3 and 2-4, respectively.

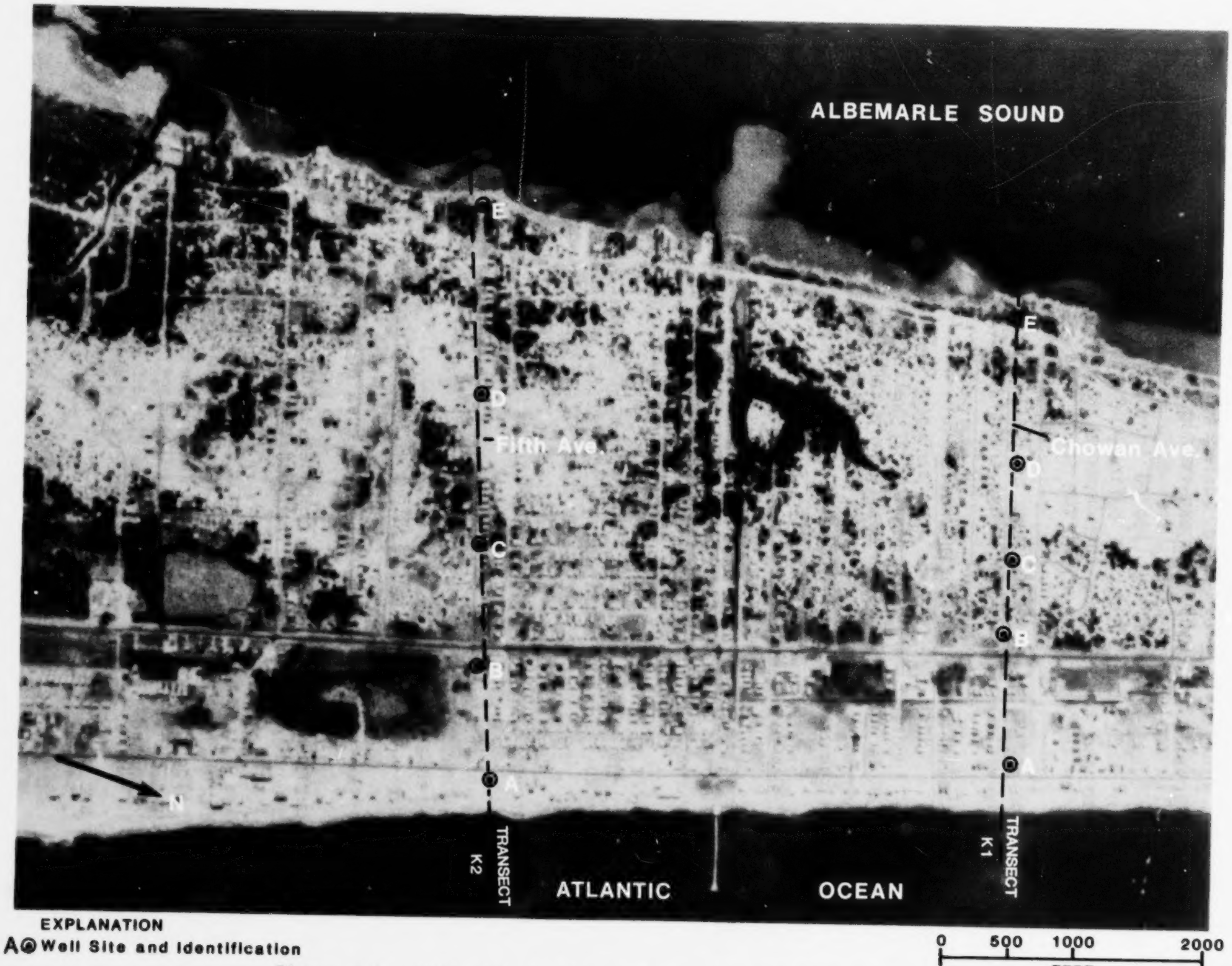
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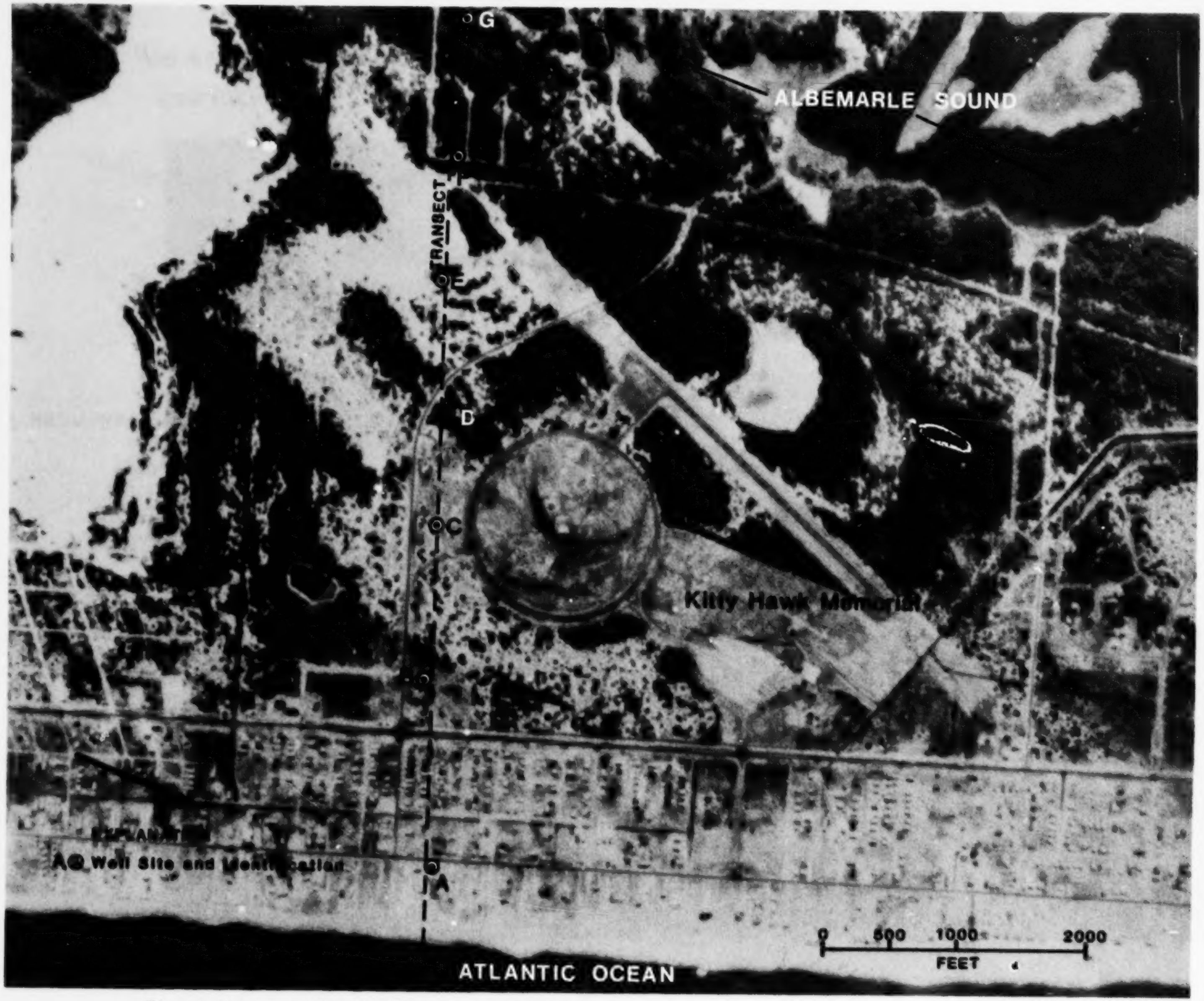
Figure 2-1. Well site locations for medium and high population density transects in Kill Devil Hills.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500
1000
2000
FEET
ATLANTIC OCEAN

Figure 2-2. Well site locations for low population density transect in Kill Devil Hills.

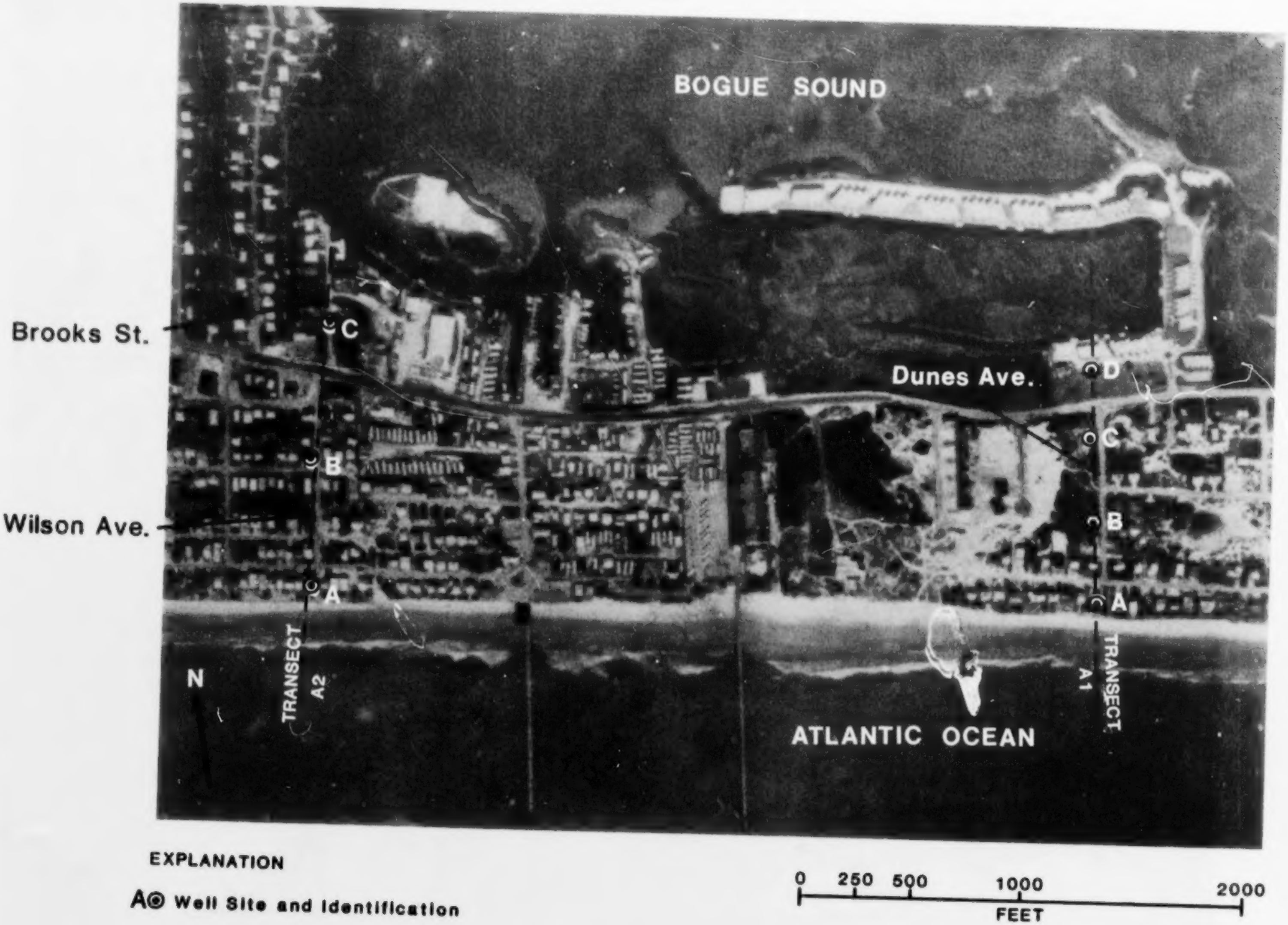

BOGUE SOUND
Brooks St.
Wilson Ave.
Dunes Ave.
C
B
A
D
C
B
A
TRANSECT A2
TRANSECT A1
N
ATLANTIC OCEAN
EXPLANATION
A◎ Well Site and Identification
0 250 500 1000 2000
FEET

Figure 2-3. Well site locations for high population density transects in Atlantic Beach.

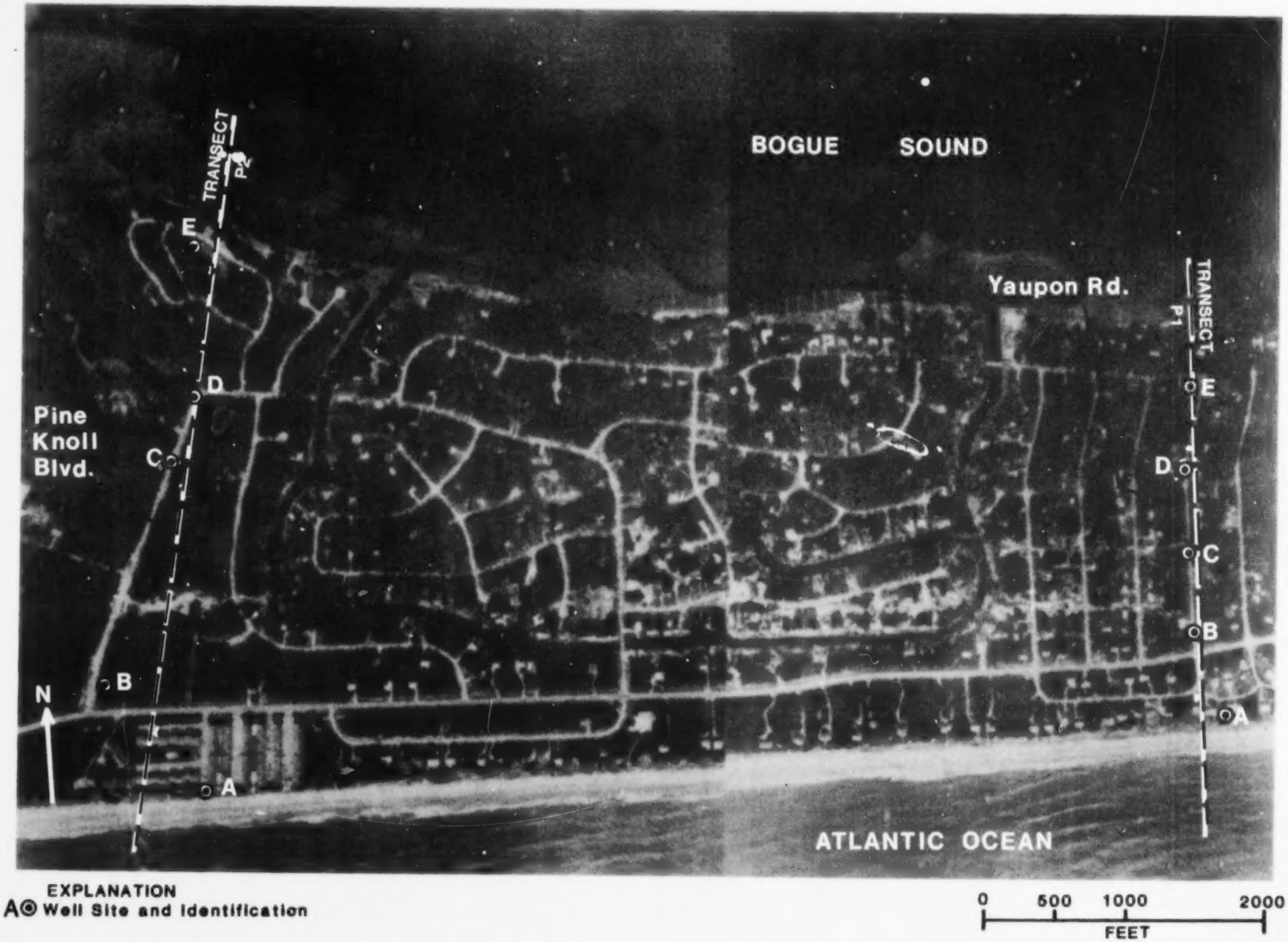

BOGUE SOUND
Yaupon Rd.
TRANSECT P2
TRANSECT P1
E
D
C
B
A
Pine Knoll Blvd.
N
ATLANTIC OCEAN
EXPLANATION
A◎ Well Site and Identification
0
500
1000
2000
FEET

Figure 2-4. Well site locations for medium and low population density transects in Pine Knoll Shores.

Two transect lines were located in the Surf City study area (Figure 2-5). One line, Transect S1, was located along Pender Avenue in an area with a medium population density. The second line, Transect S3, was located along Goldsboro Avenue in an area of relatively high population.

Wells were not constructed in an area of low population density in Surf City. Alternate low population density transect lines were identified but permission to construct wells along these transects could not be obtained from the residents.

Transect length, or island width, varied within a study area and between study areas. Transect lengths are summarized in Table 2-1.

2.1.2 Well Sites and Well Construction

Well sites were spaced along each transect with one site located near the ocean, one site located near the sound and generally one or more sites located at approximately equal intervals between the ocean and sound sites (see Figures 2-1 through 2-5).

Multiple wells were completed at many of the well sites. Each ocean and sound site has multiple wells as does each site at the midpoint in a transect. Additionally, all sites along the high population density transects were completed with multiple wells. Monitoring well construction at each site is summarized in Table 2-2. Detailed construction records for each well site are presented in Appendix A.

Sites with multiple monitoring wells have each well completed at a different depth. One well is completed near the water table surface. A second well is generally completed midway between the water table surface and the top of clayey confining beds that form the base of the shallow aquifer. A third well is completed immediately above the top of the confining beds. At some transects, the midpoint well site has a fourth well completed immediately below the clayey confining beds.

Borings for the monitoring wells were drilled in one of two ways. Borings with a total depth of less than about 20 feet were generally advanced using a hollow stem auger. Deeper borings were generally drilled using mud rotary techniques. The borehole for each well was drilled large enough to assure a two-inch clearance between the borehole wall and the well pipe.

Most borings were completed as two-inch diameter monitoring wells (see Table 2-2). These wells were constructed using schedule 40 PVC pipe and screen. The screen slot size was generally 0.010 inches and the screen length was generally five feet. Bentonite or cement grout was used to fill the annulus between the borehole and the well pipe in areas where confining layers were penetrated by the borehole. The borehole was generally allowed to collapse against the well pipe in other areas of the hole. The wells were finished at land surface using steel protector pipes with locking caps. The protector pipes were set in a cement or bentonite surface seal.

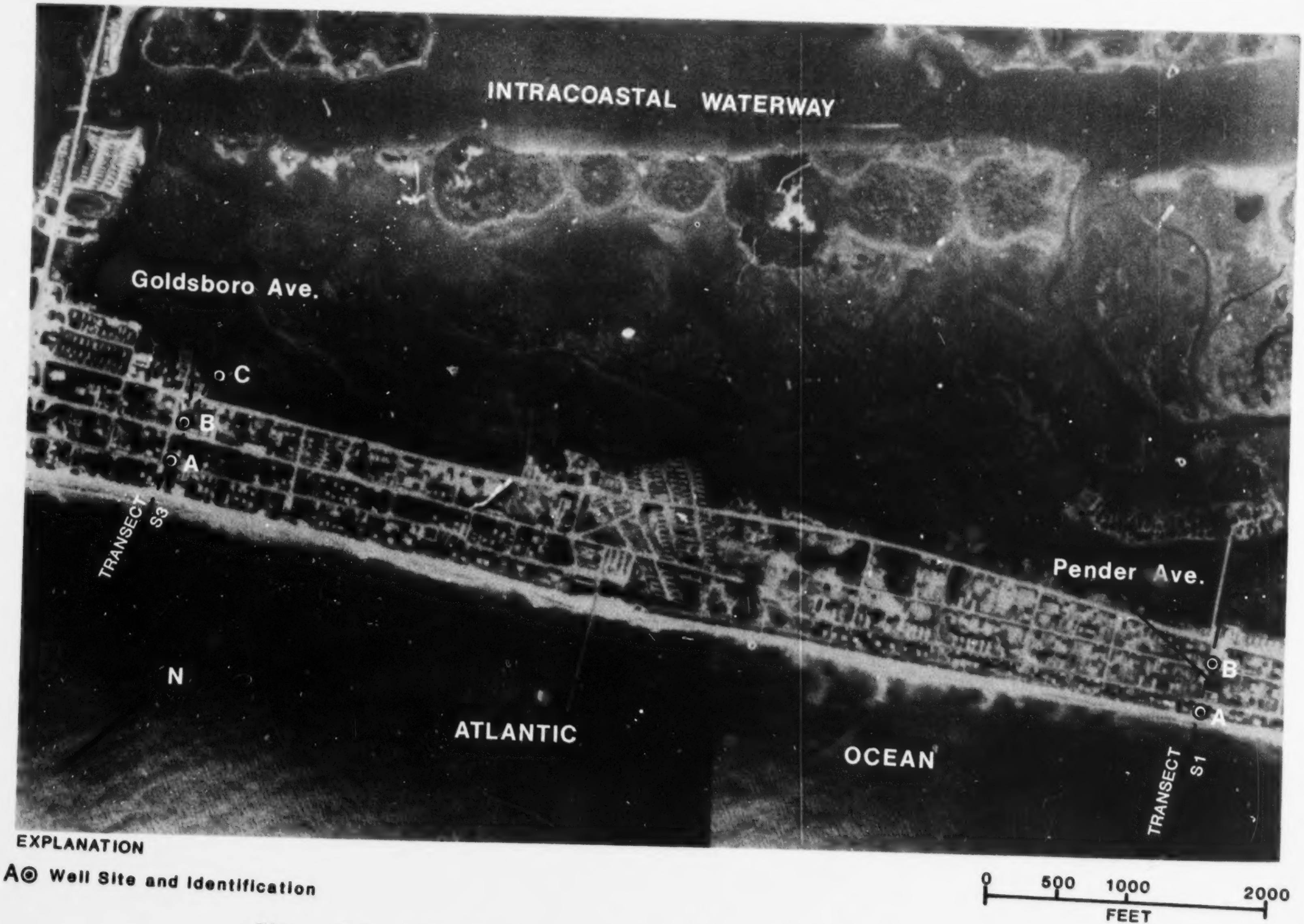

INTRACOASTAL WATERWAY
Goldsboro Ave.
C
B
A
TRANSECT S3
N
ATLANTIC
OCEAN
Pender Ave.
B
A
TRANSECT S1
EXPLANATION
A⊙ Well Site and Identification
0
500
1000
2000
FEET

Figure 2-5. Well site locations for medium and high population density transects in Surf City.

TABLE 2-1

SUMMARY OF TRANSECT LENGTHS

Transect location	Transect ID	Transect length (ft)
Kill Devil Hills	K1	4,120
	K2	4,920
	K3	7,800
Atlantic Beach	A1	1,310
	A2	1,800
Pine Knoll Shores	P1	2,930
	P2	3,920
Surf City	S1	600
	S3	875

TABLE 2-2

SUMMARY OF MONITORING WELL CONSTRUCTION

Well ID(1)	Depth of borehole (ft)	Depth to bottom of screen (ft)	Screen length (ft)	Well diameter (inches)
KILL DEVIL HILLS Transect K1				
K1A1	15.0	13.0	5	2
K1A2	40.5	40.3	5	2
K1A3	86.5	70.0	5	2
K1B1	12.0	10.0	5	2
K1C1	13.0	11.0	5	2
K1C4	40.0	36.0	5	2
K1C5	86.5	61.1	5	2
K1D1	13.0	11.0	5	2
K1E1	12.0	9.0	5	2
K1E2	40.0	39.3	5	2
K1E3	96.5	64.0	5	2
Transect K2				
K2A1	16.0	14.0	5	2
K2A2	46.0	45.8	5	2
K2A3	110.0	95.0	5	2
K2B1	10.0	10.0	5	2
K2B2	40.0	39.7	5	2
K2B3	81.5	75.0	5	2
K2C1	10.0	10.0	5	2
K2C2	41.1	39.0	5	2
K2C3	91.5	80.0	5	2
K2C4	120.0	100.0	5	2
K2D1	12.0	11.0	5	2
K2D2	40.0	39.0	5	2
K2D3	85.0	76.0	5	2
K2E1	9.0	9.0	5	2
K2E2	40.5	40.3	5	2
K2E3	86.5	78.0	5	2

TABLE 2-2
(continued)
SUMMARY OF MONITORING WELL CONSTRUCTION

Well ID(1)	Depth of borehole (ft)	Depth to bottom of screen (ft)	Screen length (ft)	Well diameter (inches)
KILL DEVIL HILLS (cont'd) Transect K3				
K3A1	14.0	14.0	5	2
K3A2	40.0	39.4	5	2
K3A2B	61.0	60.0	5	2
K3A3B	106.5	98.0	5	2
K3B1	9.0	9.0	5	2
K3C1	9.0	9.0	5	2
K3D1	13.6	13.0	5	6
K3D2	47.0	46.5	20	4
K3D3B	86.5	79.0	5	2
K3E1	10.0	9.5	5	2
K3F1	12.0	11.0	5	2
K3G1	15.0	9.4	5	2
K3G2	41.5	39.5	5	2
K3G3	87.0	75.0	5	2
ATLANTIC BEACH Transect A1				
A1A1	15.0	11.0	5	2
A1A3	50.0	42.0	5	2
A1B1	13.0	11.0	5	2
A1B3	42.0	35.0	5	2
A1C1	15.0	11.0	5	2
A1C3	37.0	32.0	5	2
A1D1	20.0	13.0	5	2
A1D2	52.0	40.0	5	2
A1D3	110.0	96.0	5	2
Transect A2				
A2A1	15.0	13.5	5	2
A2A3	41.5	32.0	5	2
A2A4	70.0	67.9	5	2

TABLE 2-2
(continued)
SUMMARY OF MONITORING WELL CONSTRUCTION

Well ID(1)	Depth of borehole (ft)	Depth to bottom of screen (ft)	Screen length (ft)	Well diameter (inches)
Atlantic Beach (cont'd) Transect A2 (cont'd)				
A2B1	12.0	9.7	5	2
A2B3	37.0	30.0	5	2
A2B4	165.0	90.0	5	2
A2C1	13.0	11.0	5	2
A2C3	31.5	22.0	5	2
A2C4	75.0	70.0	5	2
PINE KNOLL SHORES Transect P1				
P1A1	21.0	17.0	5	2
P1A2	45.0	40.0	5	2
P1A3	66.5	60.0	5	2
P1B1	19.0	16.6	5	2
P1C1	13.0	12.0	5	2
P1C2	35.0	33.0	5	2
P1C3	66.5	55.8	5	2
P1C4	79.0	73.0	5	2
P1D1	15.0	15.0	5	2
P1E1	15.0	12.0	5	2
P1E2	35.0	34.0	5	2
P1E3	61.5	56.0	5	2
Transect P2				
P2A1	20.0	19.0	5	2
P2A2	40.0	36.7	5	2
P2A3	67.0	60.0	5	2
P2B1	16.5	14.0	5	2
P2C1	13.0	10.6	5	6
P2C2	35.0	30.0	15	4
P2C3	51.5	37.0	5	2
P2C4	75.0	69.5	5	2
P2D1	15.0	14.0	5	2
P2E1	15.0	13.0	5	2
P2E2	30.0	27.0	5	2
P2E3	51.5	42.0	5	2

TABLE 2-2
(continued)
SUMMARY OF MONITORING WELL CONSTRUCTION

Well ID(1)	Depth of borehole (ft)	Depth to bottom of screen (ft)	Screen length (ft)	Well diameter (inches)
SURF CITY Transect S1				
S1A1	15.0	14.7	5	2
S1A2	41.0	37.0	5	2
S1A3	60.0	60.0	5	2
S1B1	16.0	11.0	5	2
S1B2	33.0	31.0	5	2
S1B3	70.0	70.0	5	2
Transect S3				
S3A1	20.0	17.4	5	2
S3A2	34.0	31.0	4.5	2
S3A3	70.0	65.0	5	2
S3B1	18.0	14.2	5.6	6
S3B2	30.0	29.8	5	2
S3B3	52.0	48.6	5	2
S3B4	135.0	124.0	5	2
S3B5	31.5	28.4	4.2	4
S3C1	16.0	11.0	5	2
S3C2	30.0	27.0	5	2
S3C3	80.0	70.0	5	2

---

(1) Each well is identified by transect, well site and a sequence number. The first two characters of the well number identify the transect. The third character identifies the well site location within the transect. The remaining characters identify the individual well at the well site.

One borehole in each study area was completed as a four-inch diameter monitoring well (see Table 2-2). These wells were constructed to serve as the pumped wells for conducting aquifer pumping tests.

One borehole in each study area was completed as a six-inch diameter monitoring well (see Table 2-2). A water-level recorder was installed over each of these wells to collect a continuous record of water-table fluctuations in the study areas.

The larger diameter monitoring wells were completed in a manner similar to the two-inch diameter wells. Schedule 40 PVC pipe and screen were used to construct these wells and the wells were finished at land surface using steel protector pipes with locking caps. The protector pipes were set in a cement or bentonite surface seal.

A lithologic sampling record was completed for each well site by a geologist who monitored drilling activities at the site. The record was constructed using split-spoon samples taken from one or more of the boreholes drilled at the site, supplemented by an examination of cuttings during drilling operations. A lithologic sampling record for each well site is presented in Appendix B.

Each monitoring well was developed by pumping. Water was pumped from the well until the well produced sediment-free water, or for a minimum of one hour, if clear sediment-free water was produced in less time.

2.2 Installation of Tidal Gauges

Two tidal gauges were installed in each study area. One tidal gauge was established in the sound and one tidal gauge was established in the ocean. The ocean tidal gauges consisted of two-inch diameter PVC pipes with locking caps that were attached to ocean fishing piers. The sound tidal gauges were metal staff gauges graduated in 0.02-foot intervals that were attached to piers in the sounds.

2.3 Aquifer Testing

An aquifer pumping test was conducted in each study area to collect data that could be used to determine the hydraulic properties of the shallow aquifer in that area. These tests included pumping a constant volume of water from the test well and generally measuring water levels in the test well and nearby wells during pumping and for approximately two hours after pumping stopped.

The water-level data collected during testing were used to compute the hydraulic properties of the aquifer systems. The modified Theis nonequilibrium formula (Ferris et al., 1962), the Theis recovery formula (Ferris et al., 1962), and procedures developed by Stallman for evaluating test data from partially penetrating wells in unconfined aquifers (Lohman, 1972) were used for the computations. The aquifer pumping test results are summarized in Table 2-3. A detailed description of each test is presented in Appendix C.

TABLE 2-3

SUMMARY OF AQUIFER PUMPING TEST RESULTS

Location	Well	Transmissivity (gpd/ft)	Horizontal hydraulic conductivity (gpd/ft^2)	Vertical hydraulic conductivity (gpd/ft^2)	Storage coefficient	Specific storage (1/ft)	Method of analysis
Kill Devil Hills	K3D2	11,100	555	-	-	-	Modified Theis nonequilibrium
	K3D2	10,700	535	-	-	-	Theis recovery
AVG.		10,900	545				
Pine Knoll Shores	P2C2	13,300	377	-	-	-	Modified Theis nonequilibrium
	P2C2	17,800	504	-	-	-	Theis recovery
	P2C3	13,000	366	-	4.5×10^{-4}	1.3×10^{-5}	Modified Theis nonequilibrium
	P2C3	19,000	535	-	-	-	Theis recovery
AVG.		16,600	468		4.5×10^{-4}	1.3×10^{-5}	
Surf City	S3B2	25,100	930	-	-	-	Modified Theis nonequilibrium
	S3B5	11,900	441	-	2.0×10^{-2}	0.7×10^{-3}	Partially penetrating well
	S3B1	13,700	507	497	4.7×10^{-2}	1.7×10^{-3}	Partially penetrating well
AVG.		16,900	626	497	3.8×10^{-2}	1.4×10^{-3}	

The property of the shallow aquifers of greatest interest in this study is hydraulic conductivity. This property is a measure of an aquifer's capacity to transmit water and is the same whether the aquifer is in an unconfined or confined condition. The hydraulic conductivity of an aquifer must be known before time independent problems involving ground-water flow can be solved.

The hydraulic conductivities of the shallow aquifer systems at the three test sites are relatively uniform. The hydraulic conductivity values varied from 468 gallons per day per square foot (gpd/ft^2) at Pine Knoll Shores to 626 gpd/ft^2 at Surf City. These values are typical of those for a fairly clean sand (Freeze and Cherry, 1979) and were estimated by dividing the computed transmissivities in each area by the estimated effective saturated thickness of the shallow aquifer during the test period.

The specific storage of an aquifer is another property generally of interest in ground-water studies. Specific storage is defined as the volume of water the aquifer releases from or takes into storage per unit volume of aquifer under a unit change in head within the aquifer. The specific storage for an aquifer depends upon the degree to which the aquifer is confined. This parameter, as well as hydraulic conductivity, must be known before time dependent problems involving ground-water flow can be solved.

The specific storage of the shallow aquifer in Pine Knoll Shores indicates that this aquifer is relatively confined in the vicinity of testing. The specific storage for the shallow aquifer is 1.3×10^{-5} ft^{-1} (Table 2-3). A specific storage value of about 1×10^{-6} ft^{-1} would indicate a fully confined condition (Lohman, 1972), whereas a value of 1×10^{-2} to 1×10^{-3} ft^{-1} would probably indicate an unconfined condition. The specific storage was computed by dividing the storage coefficient determined from testing by the estimated effective saturated thickness of the aquifer during testing.

The specific storage of the shallow aquifer for Surf City indicates that the aquifer is relatively unconfined at that test site. The specific storage of the shallow aquifer there is about 1.4×10^{-3} ft^{-1} (Table 2-3).

Water-level observations during testing at Kill Devil Hills indicated that the shallow aquifer system there was at least partially confined in the vicinity of the test.

Localized layers of organic silt near land surface are responsible for the confinement observed at the aquifer pumping test sites in Kill Devil Hills and Pine Knoll Shores. One- to two-foot layers of organic silt were encountered at shallow depths at both sites. Near-surface organic silt layers were also encountered at some of the other well sites in the Kill Devil Hills and Atlantic Beach/Pine Knoll Shores study areas.

Bailing tests were performed at some well sites in an attempt to gain added information about the hydraulic properties of the shallow aquifer. The data obtained from these tests could not be interpreted with confidence and were not used. The bailing test method was developed for testing in confined aquifer systems and has limited usefulness in unconfined aquifers (Lohman, 1972).

2.4 Transect Profile and Water-Level Measuring Point Surveys

The land surface profile along each transect, referenced to mean sea level (MSL), was determined by differential surveying. This information was needed to define the relationship between land surface and the ground-water table along the transects.

The elevation of the water-level measuring point on each monitoring well and ocean tidal gauge was surveyed at the time of the topographic survey. These elevations were determined to the nearest 0.01 foot of elevation. They are used to convert depth to water measurements to equivalent mean sea level elevations.

The zero elevation for each sound tidal gauge, referenced to mean sea level, was also surveyed at the time of the topographic survey. These elevations were also determined to the nearest 0.01 foot of elevation. This information is needed to convert staff gauge readings to equivalent mean sea level elevations.

The mean sea level elevations for each monitoring well measuring point, for each ocean tidal gauge measuring point, and for the zero reading of each sound tidal gauge are tabulated in Appendix D.

Temporary bench marks were established in the vicinity of each well site and each tidal gauge. These bench marks are for providing reference elevations for replacing well casings or tidal gauges that might become damaged during the course of the study. Descriptions of each bench mark and its elevation are summarized in Appendix D.

2.5 Water-Level Data Collection Program

The depth to ground water in each monitoring well, referenced to the water-level measuring point on the well, was determined during monthly visits to the study areas. These measurements were made with a steel tape, except for the 11 November 1984 measurements in Atlantic Beach and Pine Knoll Shores, which were made with an electric water-level indicator. All of the water-level measurements were made to the nearest 0.01 foot.

Ocean and sound water levels were generally measured during monthly visits to the study areas. Ocean water levels were measured to the nearest 0.01 foot using a steel tape. Sound water levels were read to the nearest 0.01 foot directly from the staff gauge.

The "wetted tape" method was used to determine the depth to water when a steel tape was used for the measurement. This method involved chalking the lower portion of the tape, lowering a known length of tape into the monitoring well or tidal gauge stilling pipe, then retrieving the tape and noting the length of tape that had been wetted. The chalk aids in defining the wetted portion of the tape. The depth to water is the difference between the length of tape placed in the well and the length of wetted tape. The tape length lowered into the well is measured from the designated water-level measuring point for the well.

The electric water-level indicator (electric tape) used for some of the measurements reads directly the depth to water from the measuring point. The electric tape and steel tape used during the project have been checked against each other and found to agree within 0.01 foot.

Two complete sets of ground-water level measurements were generally taken at each monitoring well during a monthly visit. The normal field procedure included measuring water levels at the ocean and sound tidal gauges, then taking a complete set of ground-water level measurements along one or more of the transects in the study area, then taking another complete set of ground-water level measurements along the same transects, and then taking a final set of measurements at the ocean and sound tidal gauges. In this manner, the ground-water level measurements along a transect, together with the ocean and sound tidal measurements, could be referenced to a common instant in time.

Diurnal ground-water level fluctuations were investigated in each study area. Ground-water levels, together with ocean and sound water levels, were measured periodically over a 24-hour period in August 1984 and again in February 1985.

Tidal tables (NOAA, 1985) were used to compute ocean water levels to supplement measurements taken in the field. The ocean tidal guages occasionally would be inaccessible due to inclement weather. Also, the ocean tidal guages at Kill Devil Hills and Surf City were damaged by storms before the study was completed.

Ground-water level measurements and tidal measurements taken during the course of the study are summarized in Appendix E.

2.6 Water Sampling and Analysis Program

Ground-water quality was sampled periodically in each of the study areas. Water quality was sampled every three months along the high population density transects, once in the summer and once in the winter along the medium population density transects, and once in the winter along the low population density transects. The results of this sampling are presented in Section 3.

Additional sampling was done in the Atlantic Beach/Pine Knoll Shores study area in September 1984 immediately following hurricane Diane (see Section 3). The high population density transects were sampled to aid in defining the impact of a major storm event on ground-water quality.

Some water quality characteristics were determined from field measurements while others were determined from laboratory measurements of water samples taken in the field. The parameters measured in the field included pH, temperature, fecal coliform bacteria and specific conductance. Those measured in the laboratory included ammonia, nitrate/nitrite, chloride, sodium, total dissolved solids, orthophosphate, MBAS (methylene blue active substances), alkalinity and hardness. MBAS is a compound used in detergents and is not found naturally in the environment.

2.6.1 Sampling Procedures

Each well was purged before sampling by removing a minimum of three volumes of water from the well casing. The deep wells were generally purged using a centrifugal pump and the shallow wells were generally purged using a PVC bailer. The volume of water that needed to be removed was determined from depth to water measurements made prior to sampling and from well construction records.

Water samples for laboratory analyses were collected and preserved after the well had been purged. A peristaltic pump was used to draw water from the well and into sample containers. The types of sample containers and preservation techniques used in conjunction with sampling are summarized in Table 2-4.

The equipment used for purging and sampling the wells was decontaminated prior to its use at each well. The suction hose for the centrifugal pump and the PVC bailer were rinsed with distilled water prior to their use for purging the wells. The teflon tubing used with the peristaltic pump was also rinsed with distilled water and approximately 200 milliliters of distilled water was pumped through the hose prior to sampling each well. This decontamination procedure was considered adequate for the types of water analyses that were being performed.

Sample holding times were minimized by shipping the water samples to the chemistry laboratory at the end of each work day. The water samples were packaged in ice chests as they were collected. At the end of each day, these chests were sealed and taken to the nearest airport with overnight delivery service to Atlanta, Georgia. The chests would be flown to Atlanta in the evening and delivered to the chemistry laboratory the next morning.

Portable equipment was used for measuring some water quality characteristics in the field. Temperature and specific conductance were measured using a portable specific conductance meter. A portable pH meter was used for determining the water pH in the field. Fecal coliform bacteria were measured each day using a portable membrane filtration apparatus.

2.6.2 Analysis Procedures

Chemical analyses were performed using generally accepted procedures. Ion chromatography was used to perform analyses for ammonia,

TABLE 2-4

SUMMARY OF SAMPLE PRESERVATION AND ANALYTICAL ANALYSIS METHODS

Parameter	Sample container	Sample preservation	Maximum holding time[1]	Analytical analysis method
Ammonia	plastic	H_2SO_4 to pH<2 Cool to 4°C	28 days	Ion chromatograph(2)
Nitrate/nitrite	plastic	H_2SO_4 to pH<2 Cool to 4°C	28 days	Ion chromatograph(2)
Chloride	plastic	Cool to 4°C	28 days	Ion chromatograph(2)
Sodium, total	plastic	HNO_3 to pH<2 Cool to 4°C	6 months	Atomic absorption(3) (Method 273.1)
Total dissolved solids	plastic	Cool to 4°C	2 days	Gravimetric, dried at 180°C(3) (Method 160.1)
Orthophosphate, total	plastic	Cool to 4°C	2 days	Colorimetric(3) (Method 365.2)
MBAS	plastic	Cool to 4°C	1 day	Colormetric(3) (Method 425.1)
Alkalinity	plastic	Cool to 4°C	28 days	Colorimetric(3) (Method 310.2)
Hardness, total (mg/l as $CaCO_3$)	plastic	HNO_3 to pH<2 Cool to 4°C	6 months	Colorimetric(3) (Method 130.1)

(1) From Federal Register Vol. 49, No. 209, 26 October 1984.

(2) From manufacturer's manual.

(3) EPA (1979).

nitrate/nitrite and chloride. Procedures outlined by the United States Environmental Protection Agency (USEPA, 1979) were used to perform analyses for total sodium, total dissolved solids, orthophosphate, MBAS, alkalinity and total hardness.

2.7 Water Use Along Transects

Water use was identified along each transect. In general, water use along a transect included all water use between the two nearest streets that paralleled, and thus bracketed, the street along which the transect was located.

Wastewater disposal along the transects is assumed to be equal to water use.

2.7.1 Water Use Along Transects in Kill Devil Hills

Water used for public supply in Kill Devil Hills comes from deep wells on Roanoke Island. There are only a few private wells in the area.

Water usage is highest in the summer months and lowest in the winter months (Table 2-5). Quarterly water usage records from the Kill Devil Hills water department showed that water usage along Transects K1, K2 and K3 during 16 June to 15 September were, respectively, 3.5, 2.1 and 10.7 times greater than that during 16 December to 15 March.

Water use varied along transects as well as between transects. The variation in water use along a transect was most noticeable at Transect K3. There is a considerable amount of development between well sites K3A and K3B and very little development along the rest of the transect. The variations in water use along Transects K1, K2 and K3 for the period April 1984 to March 1985 are shown in Figure 2-6. The average water use along each transect for the period is also shown.

2.7.2 Water Use Along Transects in Atlantic Beach/Pine Knoll Shores

Water used for public supply in Atlantic Beach and Pine Knoll Shores generally comes from deep wells on Bogue Banks, although some residents along Transect P1 in Pine Knoll Shores obtain their supply from individual shallow wells.

Water usage is highest in the summer months and lowest in the winter months (Tables 2-6 and 2-7). Monthly water usage records from the Atlantic Beach water department showed that the highest water usage along Transects A1 and A2 during the study period occurred in August 1984. The lowest water usage along Transect A1 occurred in February 1985 and the lowest water usage along Transect A2 occurred in December 1984. The ratio of high to low month water usage was 8.3 for Transect A1 and 3.3 for Transect A2. In Pine Knoll Shores the ratio of high to low quarterly water usage from public supplies along Transects P1 and P2 were 2.4 and 3.5, respectively. The high water use period occurred during the quarter July to September 1984, and the low water use period occurred during the quarter January to March 1985 along both transects. These records were provided by the Carolina Water Service Company who supplies water to Pine Knoll Shores.

TABLE 2-5

SUMMARY OF WATER USAGE ALONG TRANSECTS IN KILL DEVIL HILLS(1)

	1984			1984-1985	
Transect ID	March 16-June 15	June 16-September 15	September 16 December 15	December 16-March 15	Total
K1	322.8	744.0	392.4	211.2	1,670.4
K2	650.6	1,422.2	1,002.3	683.4	3,758.5
K3	268.8	1,144.4	503.8	107.2	2,024.2

---

(1) Numbers are reported in 1,000 gallons pumped during the period.

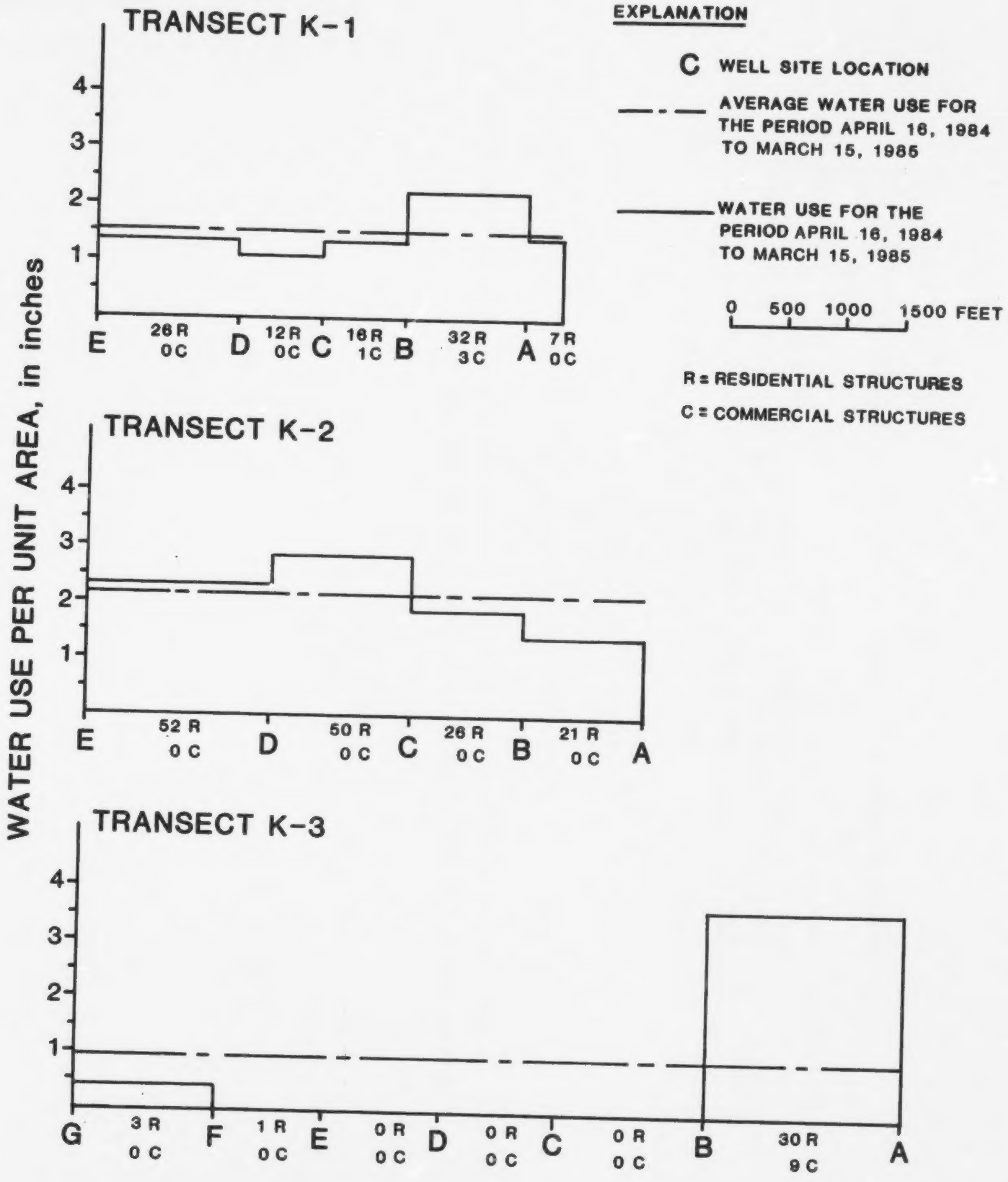


Figure 2-6. Water use along transects in Kill Devil Hills.

TABLE 2-6

SUMMARY OF WATER USAGE ALONG TRANSECTS IN ATLANTIC BEACH[1]

Transect ID	1984								1985				
	May	June	July	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	Totals
A1	254.0	596.5	673.4	692.8	359.7	212.9	190.1	257.2	172.4	83.5	141.7	260.3	3,894.5
A2	411.8	454.9	589.0	620.3	397.2	225.2	214.6	186.9	253.5	355.6	314.6	223.7	4,247.3

---

(1)Numbers are reported as 1,000 gallons pumped during the period.

TABLE 2-7

SUMMARY OF WATER USAGE ALONG TRANSECTS IN PINE KNOLL SHORES[1]

Transect ID	1984			1985	Total
	April 1 - June 30	July 1 - September 30	October 1 - December 31	January 1 - March 31	
P1 (Public supply only)	147.7	150.0	125.5	62.3	485.5
P1 (including private wells)	304.1	447.8	244.6	233.6	1,230.1
P2	1015.0	1912.9	551.5	543.4	4022.8

---

(1) Numbers are reported as 1,000 gallons pumped during the period.

Water use data for Transect P1 are presented with and without the individual private well water usage included in the numbers (Table 2-7). The private wells generally withdraw water from the shallow aquifer and thus do not present an addition of water to the shallow aquifer. Therefore, private well water usage is not needed for a water budget analysis. However, private well water usage does impact water quality in the shallow aquifer and was taken into account when analyzing groundwater quality. Water usage from private wells is based on an inventory of these along the transect and the known water use for those residents along the transect that use public supplies.

Water use varied along transects as well as between transects. The variation in water use along a transect was most noticeable at Transect P2. There is a considerable amount of development between well sites P2A and P2B and very little development along the rest of the transect. The variations in water use along Transects A1 and A2 for the period May 1, 1984 to April 30, 1985 are shown in Figure 2-7. The variations in water use along Transects P1 and P2 for the period April 1, 1984 to March 31, 1985 are shown in Figure 2-8. The average water use along each transect for the period is also shown.

2.7.3 Water Use Along Transects in Surf City

Water used for public supply in Surf City comes from deep wells located on the mainland about 1.5 miles northwest of town.

Water usage is highest during the spring months and lowest in the winter months (Table 2-8). Quarterly water usage records from the Surf City water department showed that the highest water usage along Transects S1 and S3 occurred during the period 1 April to 30 June 1984. The lowest water usage along Transect S1 occurred during the period 1 October to 31 December 1984, and the lowest water use along Transect S3 occurred during the period 1 January to 31 March 1985. The ratio of high to low month water usage was 1.6 for Transect S1 and 3.5 for Transect S3.

Water use varied along transects as well as between transects. The variation in water use along a transect was most noticeable at Transect S1. Commercial development in the vicinity of site S1B accounts for a relatively large water usage in that area of the transect as compared to the rest of the transect. The variations in water use along Transects S1 and S3 for the period 1 April 1984 to 31 March 1985 are shown in Figure 2-9. The average water use along each transect for the period is also shown.

2.8 Land Use Along Transects

Land use was identified in the vicinity of each transect. This information is useful for explaining variations in water use along transects. In general, land use inventory along a transect included all land use between the two nearest streets that paralleled, and thus bracketed, the street on which the transect was located.

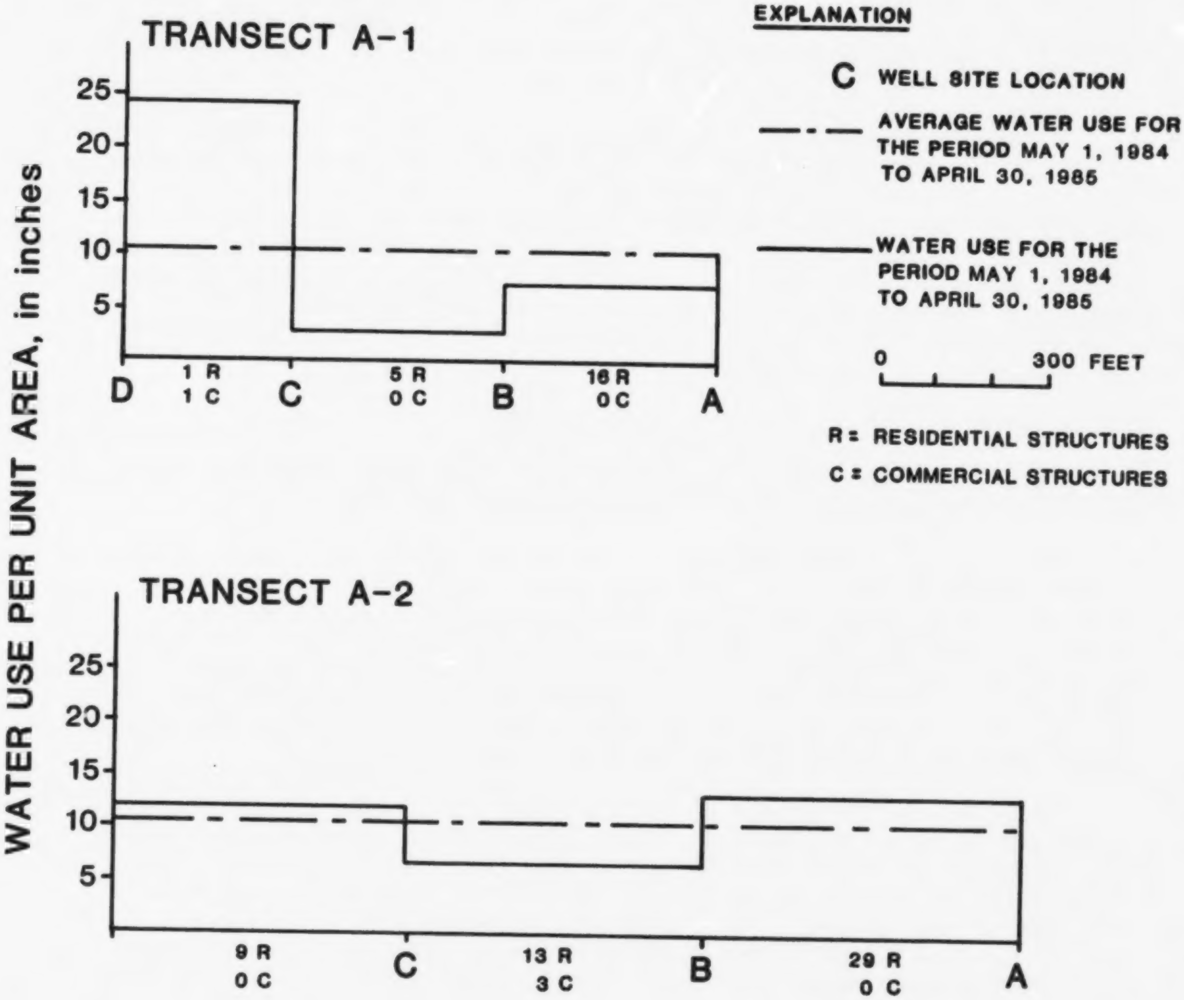


Figure 2-7. Water use along transects in Atlantic Beach.

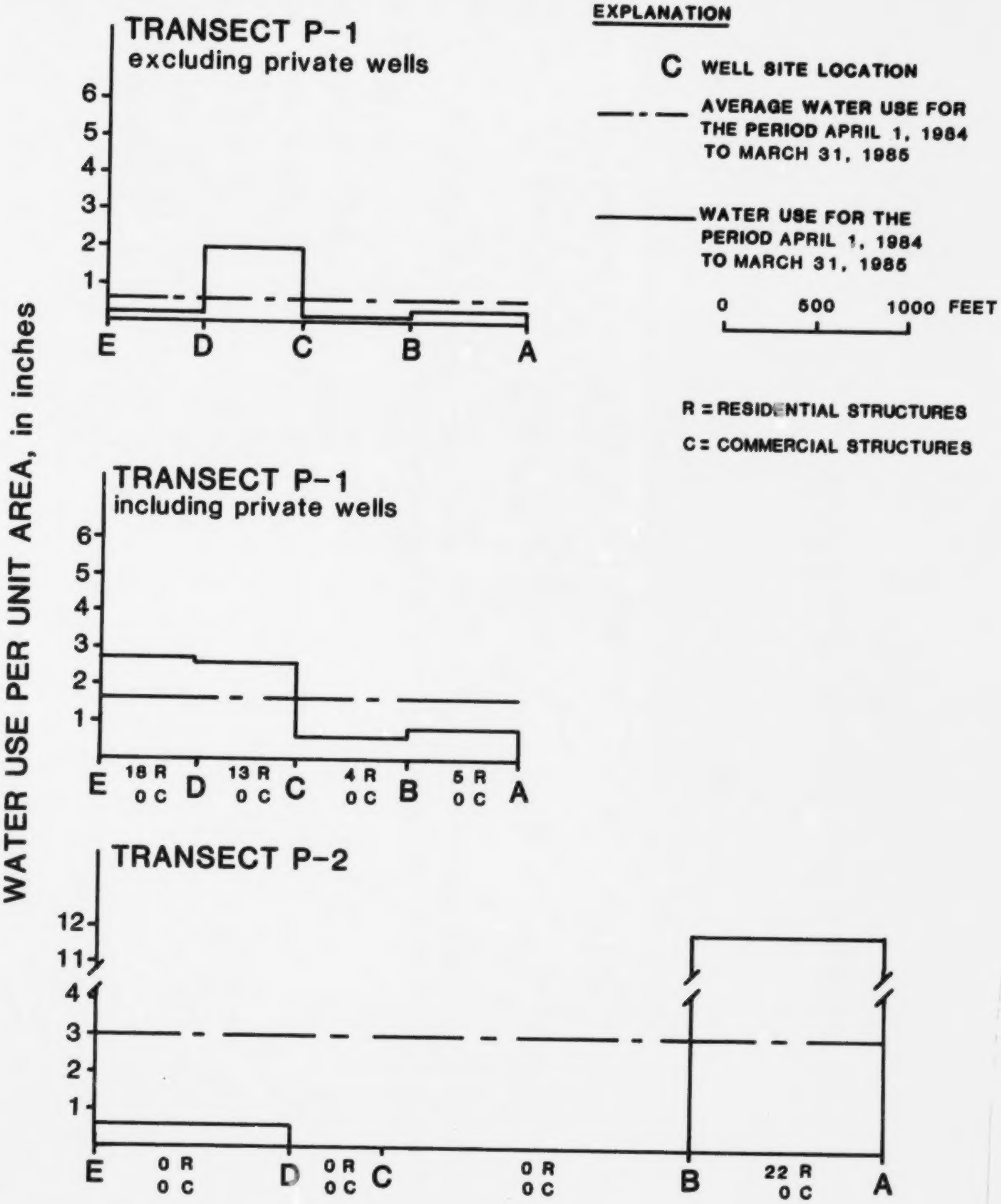


Figure 2-8. Water use along transects in Pine Knoll Shores.

TABLE 2-8

SUMMARY OF WATER USAGE ALONG TRANSECTS IN SURF CITY(1)

Transect ID	1984			1985	Total
	April 1 - June 30	July 1 - September 30	October 1 - December 31	January 1 - March 31	
S1	468.1	392.7	287.1	354.2	1,502.1
S3	641.2	484.3	338.8	183.7	1,648.0

---

(1) Numbers are reported in 1,000 gallons pumped during the period.

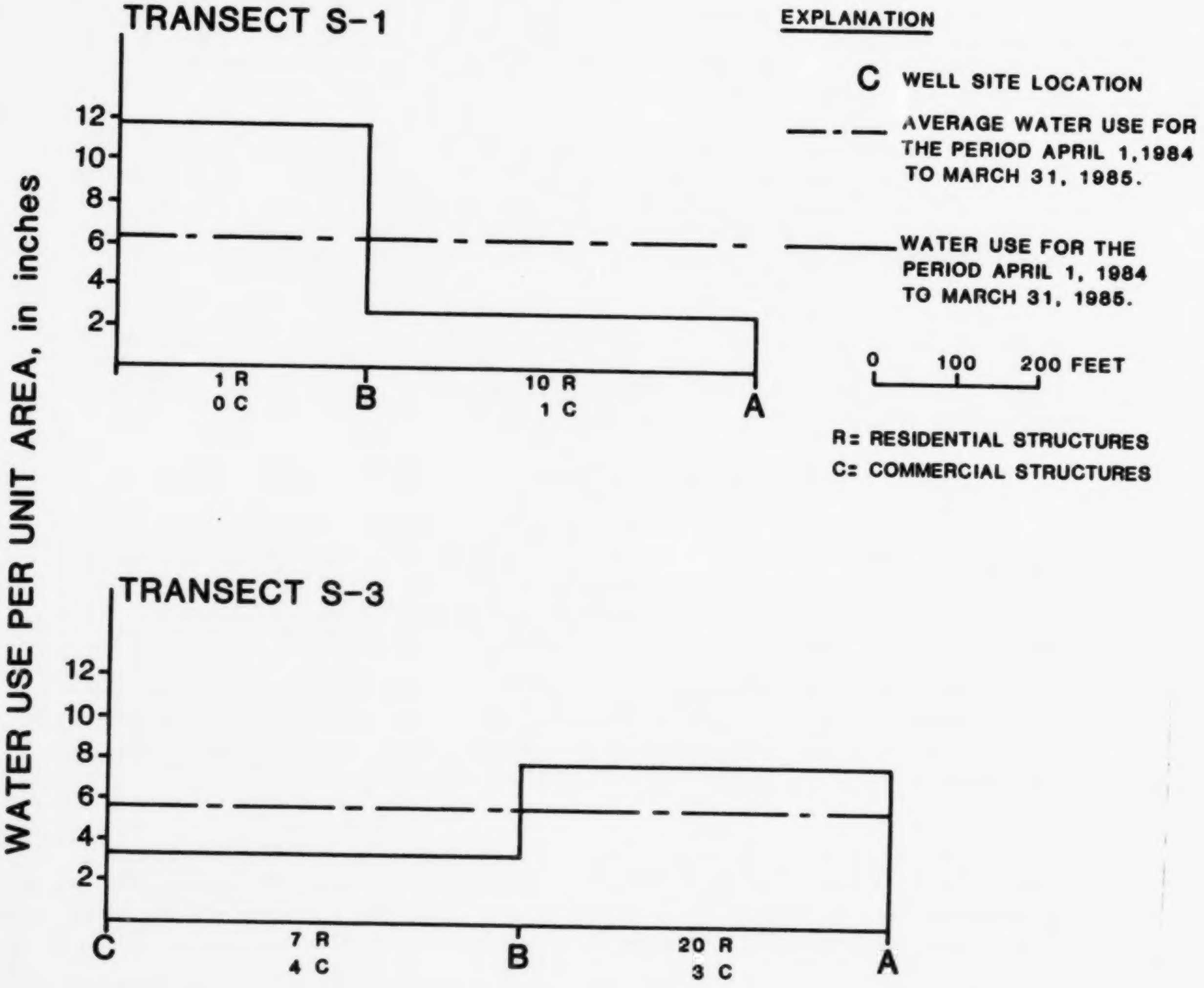


Figure 2-9. Water use along transects in Surf City.

2.8.1 Land Use Along Transects in Kill Devil Hills

Land use along Transects K1 and K2 is similar. The area between the beach and well site B along both transects is a combination of commercial and residential development. The commercial development includes restaurants, stores, motels and gas stations. This area is closest to the ocean. The area between well sites B and E along both transects is generally residential. Many of the residences along these transects are rental properties. The general distribution of land use along transects K1 and K2 is shown in Figure 2-6.

Development varies along Transect K3 (Figure 2-6). The area between the ocean and well site B is generally commercial. This area is closest to the ocean. There is essentially no development between well sites B and F. The area between well sites F and G is occupied by single family residences who probably live in the area year-round.

There is generally little or no vegetative cover along the transects. Areas not covered by manmade structures are generally composed of medium to coarse sands. The area between well sites F and G along Transect K3 is an exception. Numerous trees exist in this area, although the ground consists of medium to coarse sands.

2.8.2 Land Use Along Transects in Atlantic Beach/Pine Knoll Shores

Land use varies along Transect A1 in Atlantic Beach (Figure 2-7). The area between well sites A and C is generally residential; many of these dwellings are rental properties. A large drain field exists between well sites C and D and is adjacent to well site D. This drain field serves a large condominium complex located at the sound.

Land use along Transect A2 in Atlantic Beach is generally residential. However, many of the residential dwellings are rental properties. There also is some commercial development between well sites B and C. The general distribution of land use along Transect A2 is shown in Figure 2-7.

Land use along Transect P1 in Pine Knoll Shores is residential (Figure 2-8). The area along this transect is occupied by single family residences who generally live in the area year-round. Well site locations along Transect P1 are shown in Figure 2-4.

Development varies along Transect P2 in Pine Knoll Shores (Figure 2-8). The area between well sites A and B is occupied by condominiums. This area is closest to the ocean. There is little or no development between well sites B and D. The area between well sites D and E is currently being developed with multifamily residences.

There is little or no vegetative cover along Transects A1 and A2. Areas not covered by manmade structures are generally composed of medium to coarse sand. The drain field between well sites C and D, which has a grass cover, is an exception.

Transects P1 and P2 are both located in areas where there is considerable vegetative cover. Trees and grass grow in the areas along both of these transects.

2.8.3 Land Use Along Transects in Surf City

Land use along both Transects S1 and S3 is a combination of residential and commercial development. The residences are generally rental properties. The commercial development includes a motel located within each transect. The motel along Transect S1 is located near well site B. The motel along Transect S3 is located adjacent to well site B for that transect. The distribution of land use along transects S1 and S3 is shown in Figure 2-9.

There is little vegetative cover along the transects. Areas not covered by manmade structures are generally composed of medium to coarse sand.

3.0 HYDROGEOLOGIC CHARACTERIZATION OF THE STUDY AREAS

The results of the field data collection program, together with existing published information, were used to characterize the hydrogeology in each of the study areas. The shallow subsurface setting, ground-water occurrence and movement, the relationship between ground-water levels and precipitation, net recharge to the shallow ground-water aquifer and ground-water quality were described in detail.

The concepts of freshwater and environmental heads are used to study the movement of ground water of variable density (Lusczynski, 1961). Freshwater head at any point in ground water of variable density is defined as the level of freshwater that would be required to balance the pressure at the well screen. Environmental head is defined as the level of variable density water occurring in the aquifer above the well screen that would be required to balance the pressure at the well screen.

3.1 Hydrogeology of the Kill Devil Hills Study Area

3.1.1 General Hydrogeology

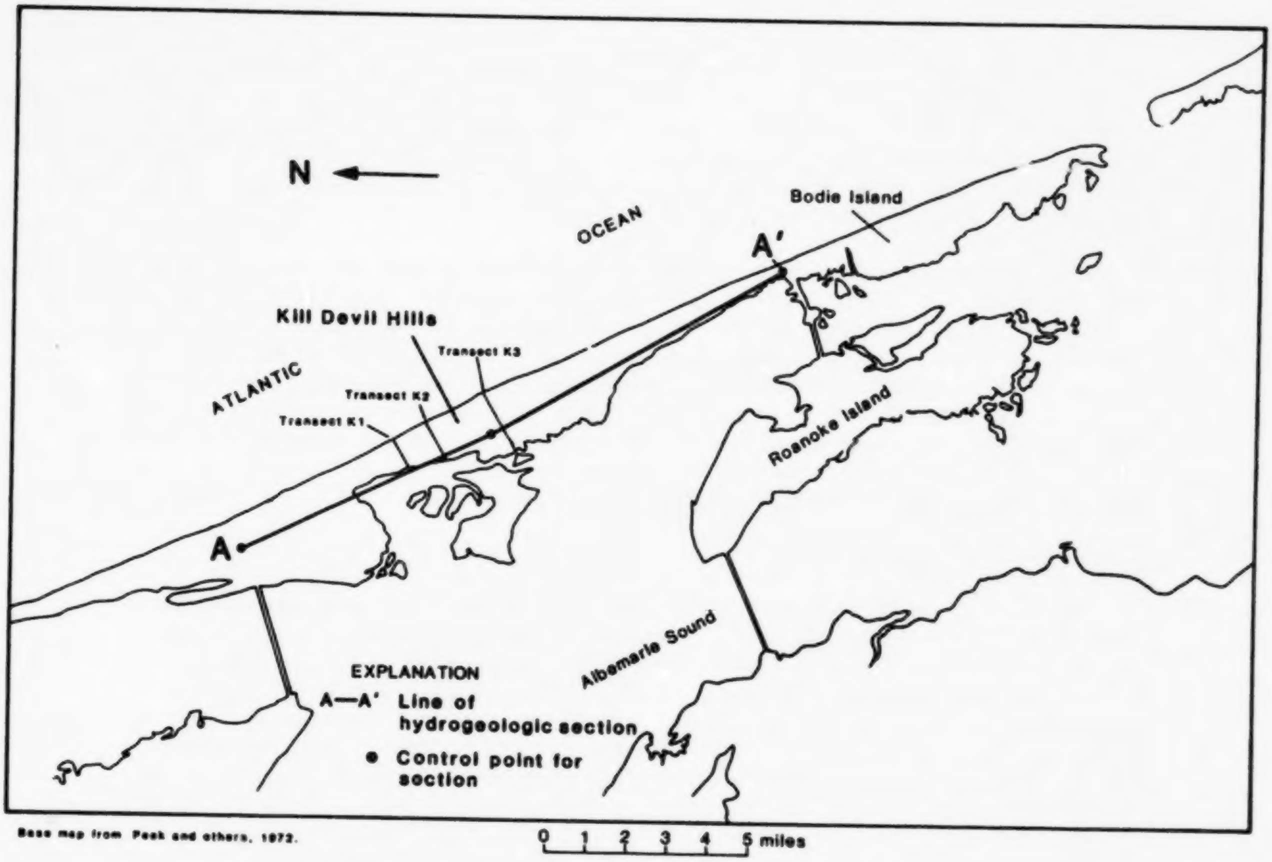
Bodie Island is underlain by three aquifers that are known to contain fresh water (Peak et al., 1972). The shallow aquifer, consisting of generally fine to medium sand, extends downward from land surface to depths varying between 30 and 80 feet. The principal aquifer, which is predominantly medium-grained sand, underlies the shallow aquifer and is about 50 feet thick. The lower aquifer underlies the principal aquifer and is composed of interbedded clay and fine sands. This aquifer varies in thickness between 50 and 100 feet. Beds of silt and clay that are 120 to 140 feet thick separate the shallow aquifer from the principal aquifer and divide the principal aquifer into two sections under the island. Beds of clay, silty clay and clayey sand, whose thickness varies from 30 to 80 feet, separate the principal and lower aquifers. A generalized hydrogeologic cross-section along a portion of Bodie Island that includes the study area is shown in Figure 3-1.

3.1.2 Hydrogeology of the Shallow Aquifer

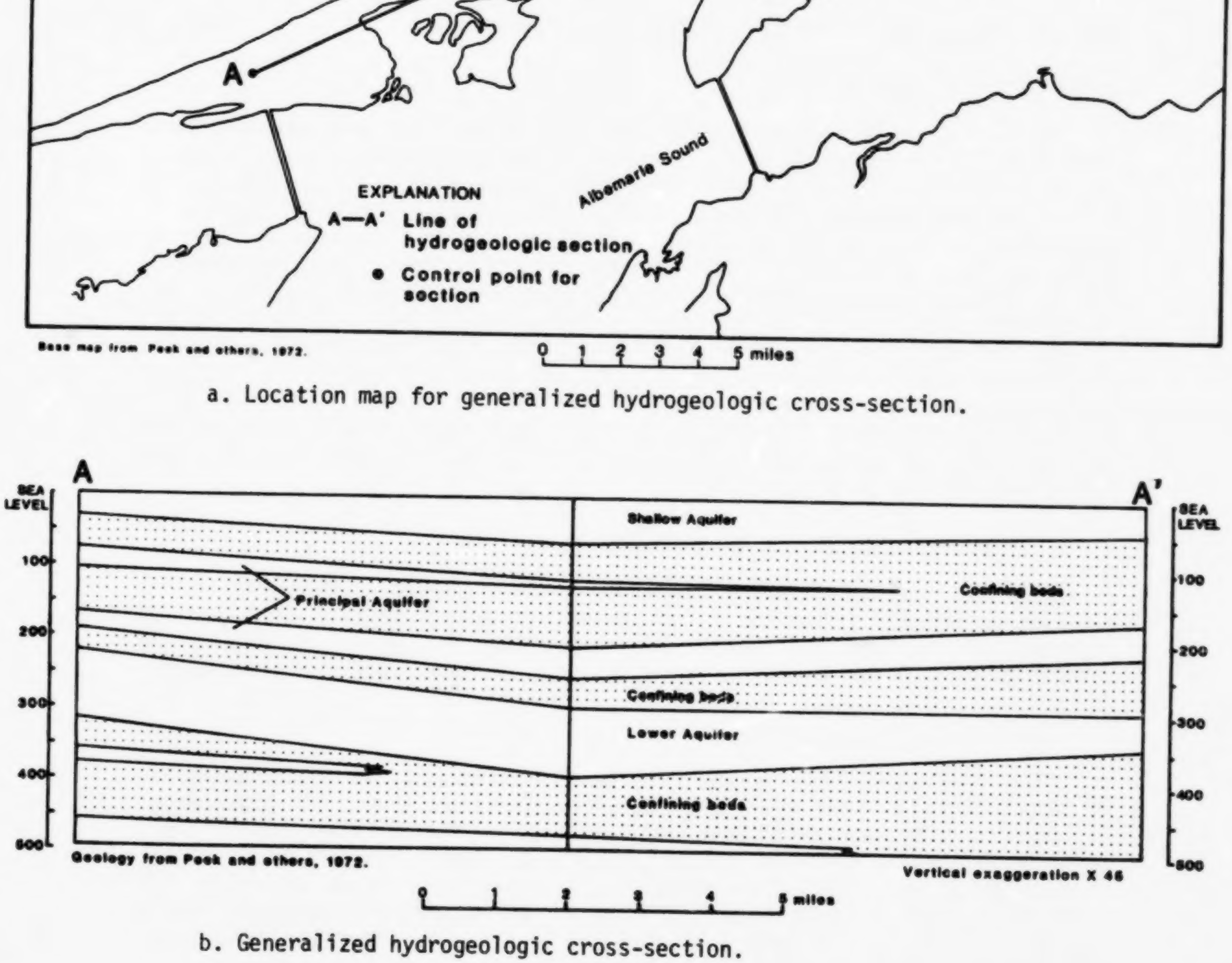
The shallow aquifer was studied for this report. This aquifer is the one impacted most by the use of on-site systems for the treatment and disposal of wastewater. Data collected from the wells drilled along Transects K1, K2 and K3 (see Figure 3-1) formed the basis for the study.

3.1.2.1 Geologic Setting

The shallow aquifer in the Kill Devils Hills area is composed mostly of fine to medium sand with some interbedded silty sands and occurrences of organic silt and peat near land surface. The near-surface organic material partially confines the water in areas where the material is present. Silts and clays interbedded with sands that occur at 65 to 100 feet below land surface form the base of the aquifer. Geologic cross-sections depicting the nature of the shallow aquifer in Kill Devil Hills are presented in Figure 3-2.


N
OCEAN
ATLANTIC
Bodie Island
A'
Kill Devil Hills
Transect K3
Transect K2
Transect K1
A
Roanoke Island
Albemarle Sound
EXPLANATION
A—A' Line of hydrogeologic section
● Control point for section
Base map from Peek and others, 1972.
0 1 2 3 4 5 miles

a. Location map for generalized hydrogeologic cross-section.


A
A'
SEA LEVEL
100
200
300
400
500
Shallow Aquifer
Principal Aquifer
Confining beds
Confining beds
Lower Aquifer
Confining beds
Geology from Peek and others, 1972.
Vertical exaggeration X 46
0 1 2 3 4 5 miles

b. Generalized hydrogeologic cross-section.

Figure 3-1. Generalized hydrogeologic cross-section for Bodie Island.

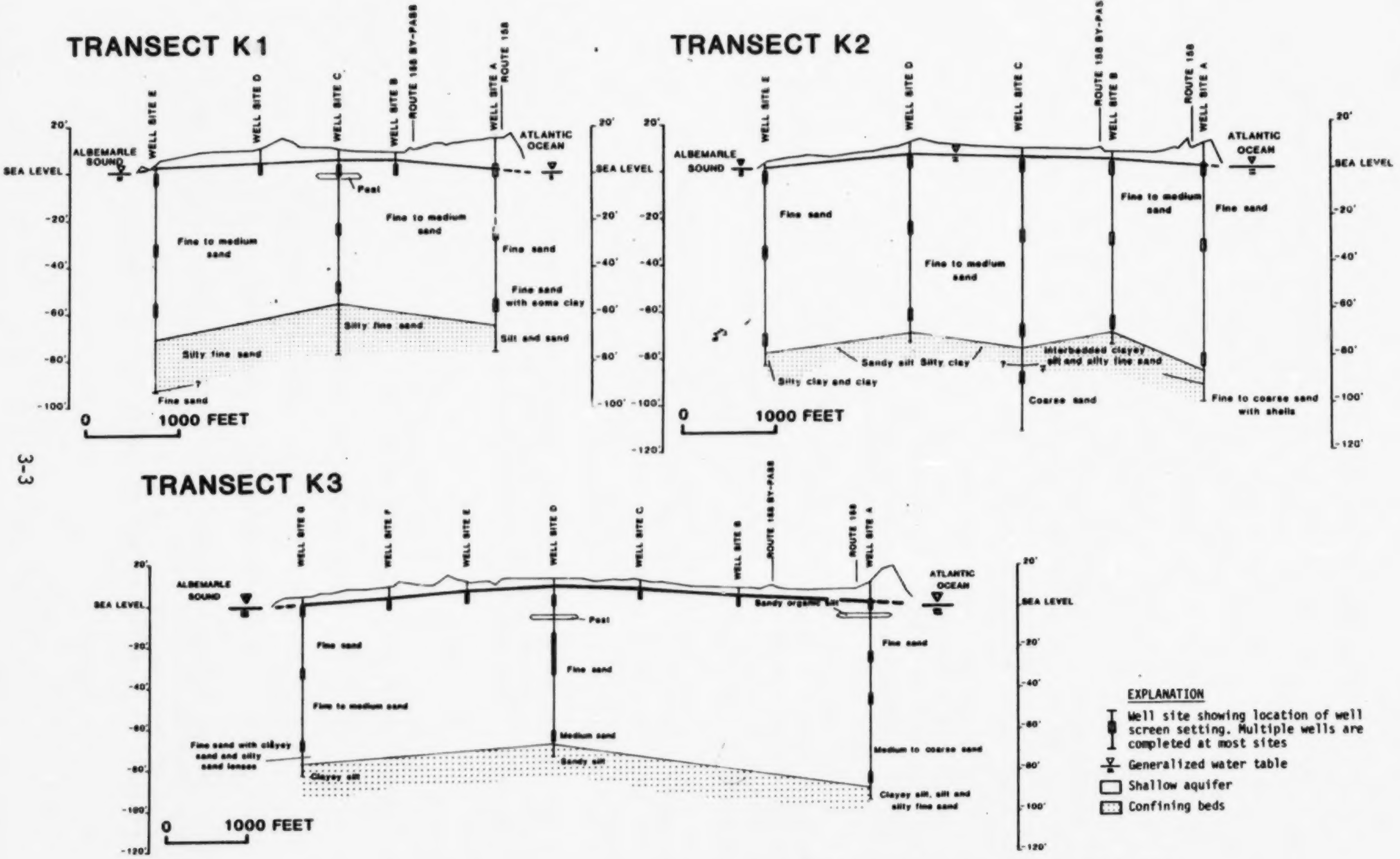

TRANSECT K1
WELL SITE E
WELL SITE D
WELL SITE C
WELL SITE B
ROUTE 158 BY-PASS
WELL SITE A
ROUTE 158
ALBEMARLE SOUND
ATLANTIC OCEAN
SEA LEVEL
20'
-20'
-40'
-60'
-80'
-100'
Peat
Fine to medium sand
Fine to medium sand
Fine sand
Fine sand with some clay
Silt and sand
Silty fine sand
Silty fine sand
Fine sand
?
0
1000 FEET
TRANSECT K2
WELL SITE E
WELL SITE D
WELL SITE C
ROUTE 158 BY-PASS
WELL SITE B
ROUTE 158
WELL SITE A
ALBEMARLE SOUND
ATLANTIC OCEAN
SEA LEVEL
-120'
Fine sand
Fine to medium sand
Fine to medium sand
Fine sand
Sandy silt
Silty clay
Silty clay and clay
Interbedded clayey silt and silty fine sand
Coarse sand
Fine to coarse sand with shells
?
0
1000 FEET
TRANSECT K3
WELL SITE G
WELL SITE F
WELL SITE E
WELL SITE D
WELL SITE C
WELL SITE B
ROUTE 158 BY-PASS
ROUTE 158
WELL SITE A
ALBEMARLE SOUND
ATLANTIC OCEAN
SEA LEVEL
Sandy organic silt
Peat
Fine sand
Fine to medium sand
Fine sand with clayey sand and silty sand lenses
Clayey silt
Fine sand
Medium sand
Sandy silt
Fine sand
Medium to coarse sand
Clayey silt, silt and silty fine sand
0
1000 FEET
EXPLANATION
Well site showing location of well screen setting. Multiple wells are completed at most sites
Generalized water table
Shallow aquifer
Confining beds

Figure 3-2. Hydrogeologic cross-sections for the shallow aquifer at Kill Devil Hills.

3.1.2.2 Ground-Water Occurrence and Movement

Ground water is present in the pore spaces of the saturated deposits that underlie Bodie Island. The intergranular pore spaces in the sands serve as the storage space for water in the shallow aquifer and as pathways for water movement. The pore spaces in clayey confining beds also serve to store water. However, these pore spaces are extremely small, making the movement of water through those deposits difficult.

Ground-water movement in the shallow aquifer is generally away from the central part of Bodie Island toward discharge points in the ocean and the sound (Figures 3-3 and 3-4). These flow directions were defined from the distribution of freshwater heads in the aquifer as measured by water levels in the monitoring wells. There were no significant differences in density of the ground water in the monitoring wells. Ground water flows from areas of higher head to areas of lower head.

Some ground water from the shallow aquifer discharges downward into the underlying confining beds. The head observed in well K2C4, completed within the confining beds, is substantially lower than that observed in the shallow aquifer. This indicates that there is downward flow into the confining beds (see Figures 3-3 and 3-4).

Normal ground-water flow patterns along the transects varied only slightly between summer and winter. Flow patterns in August 1984, which are representative of summer conditions, are shown in Figure 3-3. Flow patterns in February 1985, which are representative of winter conditions, are shown in Figure 3-4.

Heavy rains and high tides resulting from hurricane Diane in September 1984 caused reductions in ground-water flow toward the ocean along each of the transects. These changes were most pronounced in October (Figure 3-5). By December, however, ground-water flow was essentially the same as that normally observed during the study.

The ground-water flow velocity through the shallow aquifer varies from 0.1 to 1.5 feet per day (ft/day) but typically averages 0.7 ft/day (Table 3-1). This velocity was computed from the equation:

$$V = \frac{KI}{\theta} \qquad (1)$$

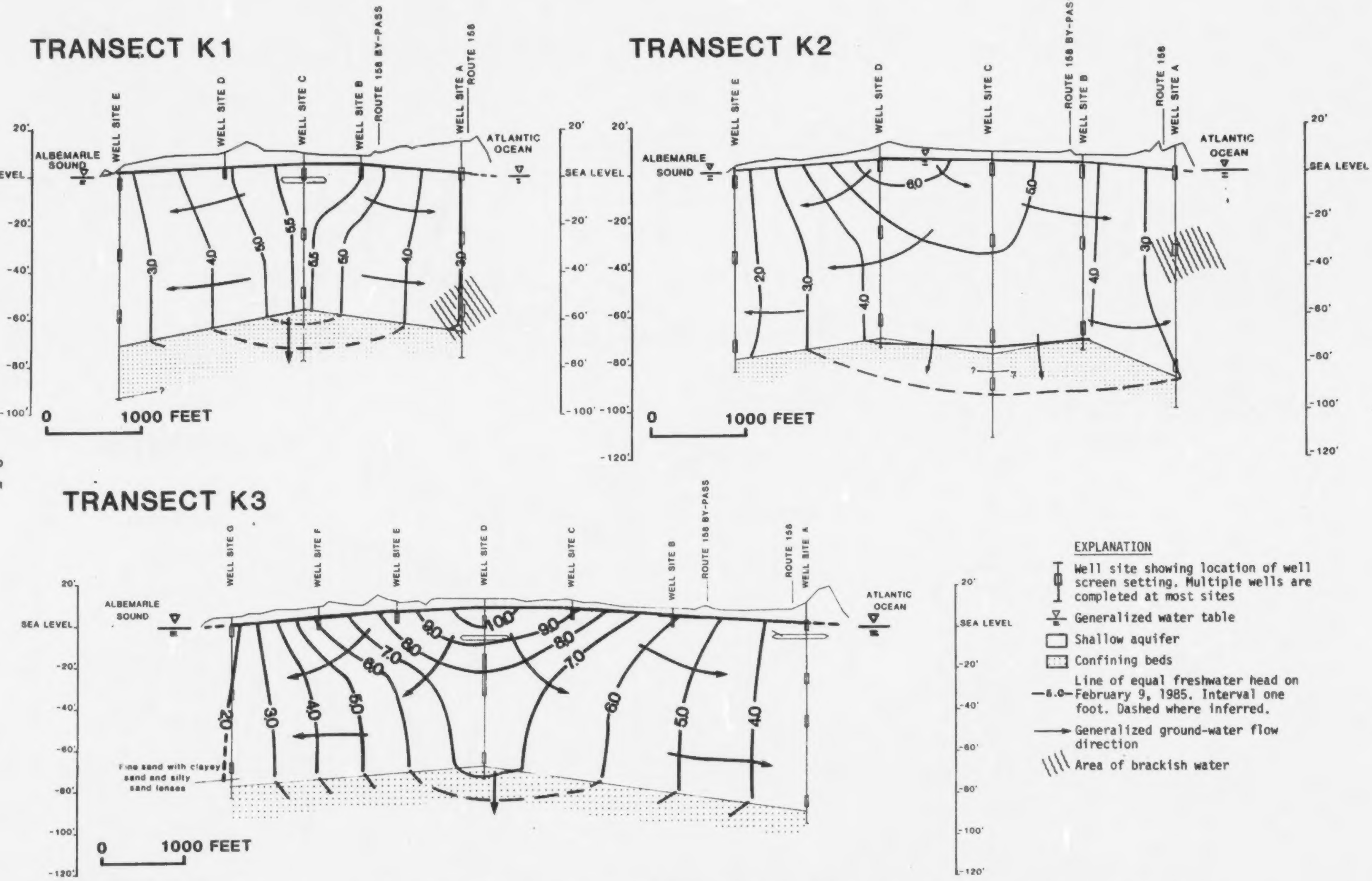
where: V = velocity, in feet per day;

K = horizontal hydraulic conductivity, in feet per day;

I = hydraulic gradient, in feet per foot; and

θ = effective porosity, no dimensions.

The horizontal hydraulic conductivity of the aquifer, as determined from aquifer testing at well K3D2, is 73 ft/day. The effective porosity of the aquifer was computed as 0.19 by correlating precipitation measured at Kill Devil Hills with changes in water levels observed in well K3D1



TRANSECT K1

TRANSECT K2

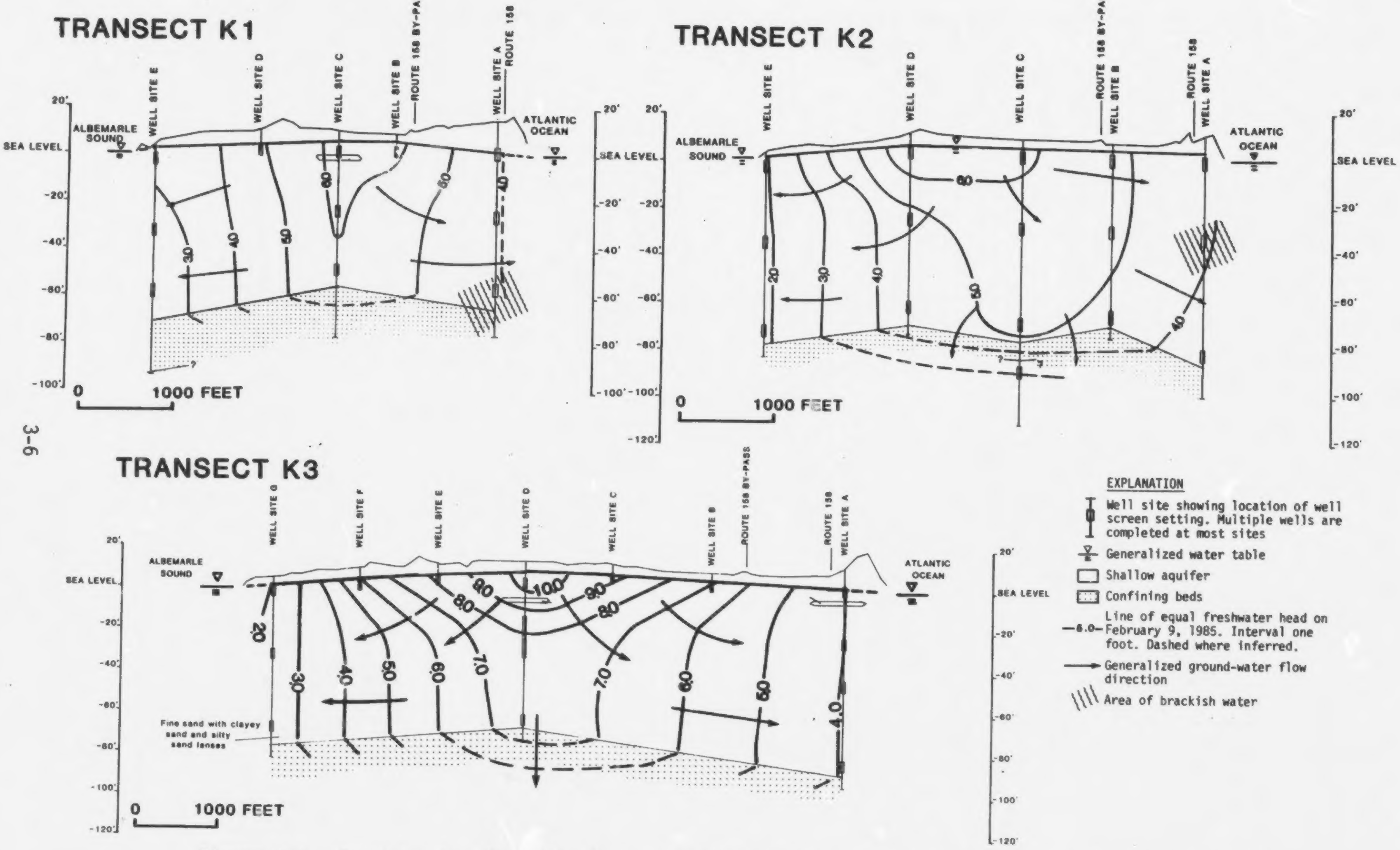
TRANSECT K3

WELL SITE E
WELL SITE D
WELL SITE C
WELL SITE B
ROUTE 158 BY-PASS
WELL SITE A
ROUTE 158
WELL SITE F
WELL SITE G
ALBEMARLE SOUND
ATLANTIC OCEAN
20'
SEA LEVEL
-20'
-40'
-60'
-80'
-100'
-120'
0
1000 FEET
2.0
3.0
4.0
5.0
5.5
6.0
7.0
8.0
9.0
10.0
?
Fine sand with clayey sand and silty sand lenses

EXPLANATION

- Well site showing location of well screen setting. Multiple wells are completed at most sites
- Generalized water table
- ☐ Shallow aquifer
- ▨ Confining beds
- —6.0— Line of equal freshwater head on February 9, 1985. Interval one foot. Dashed where inferred.
- → Generalized ground-water flow direction
- \\\\ Area of brackish water

Figure 3-3. Ground-water flowpaths in the shallow aquifer at Kill Devil Hills on August 17. 1984.



TRANSECT K1
TRANSECT K2
TRANSECT K3
WELL SITE A
WELL SITE B
WELL SITE C
WELL SITE D
WELL SITE E
WELL SITE F
WELL SITE G
ROUTE 158
ROUTE 158 BY-PASS
ALBEMARLE SOUND
ATLANTIC OCEAN
SEA LEVEL
20'
-20'
-40'
-60'
-80'
-100'
-120'
0
1000 FEET
2.0
3.0
4.0
5.0
6.0
7.0
8.0
9.0
10.0
Fine sand with clayey sand and silty sand lenses
EXPLANATION
Well site showing location of well screen setting. Multiple wells are completed at most sites
Generalized water table
Shallow aquifer
Confining beds
—6.0— Line of equal freshwater head on February 9, 1985. Interval one foot. Dashed where inferred.
Generalized ground-water flow direction
Area of brackish water

Figure 3-4. Ground-water flowpaths in the shallow aquifer in Kill Devil Hills on February 9, 1985.

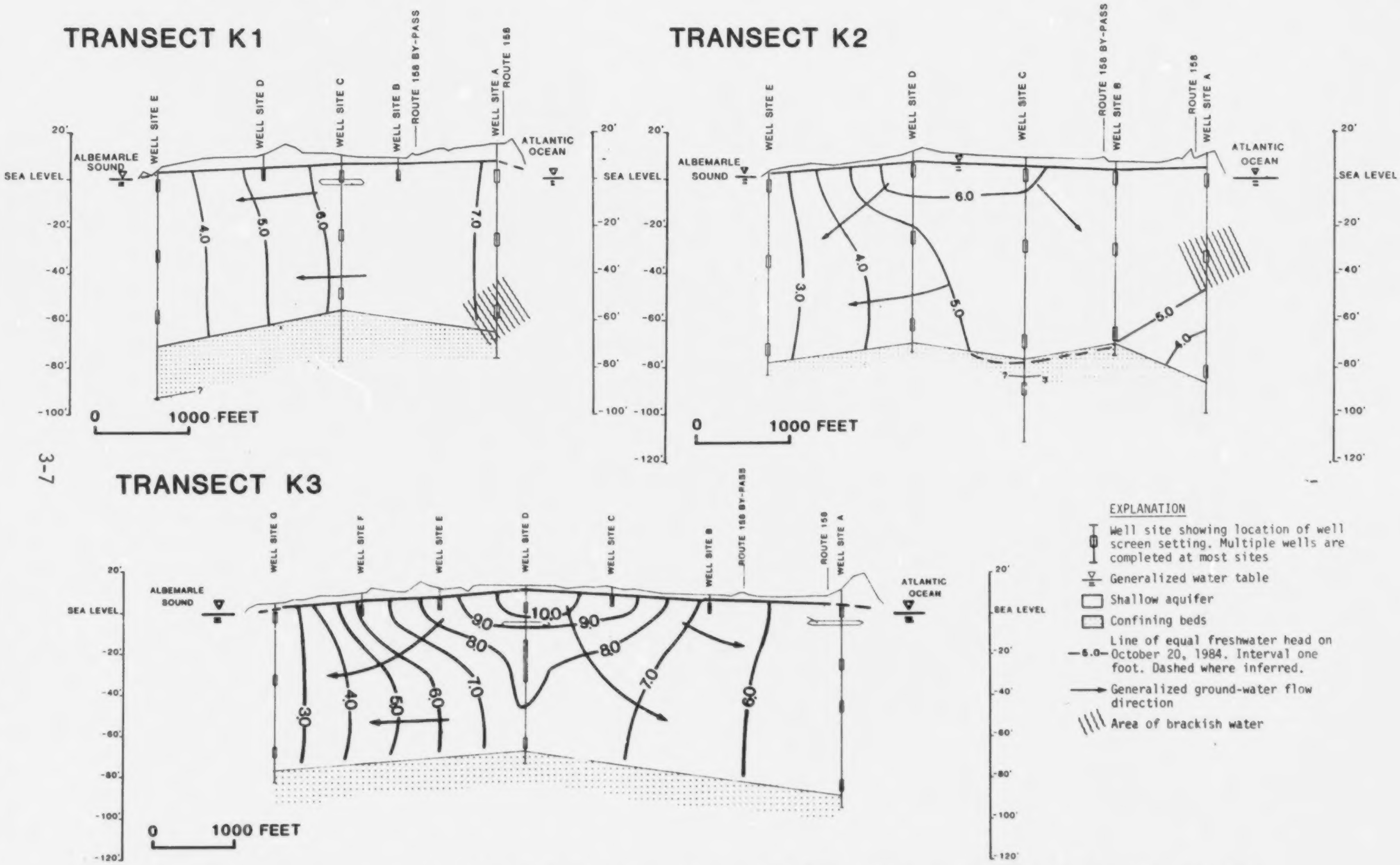

TRANSECT K1
TRANSECT K2
TRANSECT K3
ALBEMARLE SOUND
ATLANTIC OCEAN
WELL SITE A
WELL SITE B
WELL SITE C
WELL SITE D
WELL SITE E
WELL SITE F
WELL SITE G
ROUTE 158
ROUTE 158 BY-PASS
SEA LEVEL
20'
-20'
-40'
-60'
-80'
-100'
-120'
0
1000 FEET
3.0
4.0
5.0
6.0
7.0
8.0
9.0
10.0
?
EXPLANATION
Well site showing location of well screen setting. Multiple wells are completed at most sites
Generalized water table
Shallow aquifer
Confining beds
—5.0— Line of equal freshwater head on October 20, 1984. Interval one foot. Dashed where inferred.
Generalized ground-water flow direction
Area of brackish water

Figure 3-5. Ground-water flowpaths in the shallow aquifer at Kill Devil Hills on October 20, 1984.

TABLE 3-1

GROUND-WATER FLOW VELOCITIES AND TRAVEL TIMES ALONG TRANSECTS IN KILL DEVIL HILLS

Site	Distance between sites (feet)	Mean water-table elevation (MSL)	Hydraulic gradient between sites (feet/foot)	Flow velocity (feet/day)	Travel time between sites (days)	Cumulative travel time to sound or ocean (days)	Remarks
Transect K1							
C		6.2				0	Sound side of transect
	800		1.38×10^{-3}	0.53	1520		
D		5.1				1520	
	1075		1.86×10^{-3}	0.71	1500		
E		3.1				3020	
C		6.2				0	Ocean side of transect
	625		3.20×10^{-4}	0.12	5090		
B		6.0				5090	
	1000		1.80×10^{-3}	0.69	1450		
A		4.2				6540	
Transect K2							
D		6.9				0	Sound side of transect
	1475		3.32×10^{-3}	1.28	1160		
E		2.0				1160	
D		6.9				0	Ocean side of transect
	1225		7.35×10^{-4}	0.28	4340		
C		6.0				4340	
	950		1.05×10^{-3}	0.40	2350		
B		5.0				6690	
	925		1.40×10^{-3}	0.54	1710		
A		3.7				8400	
Transect K3							
D		10.4				0	Sound side of transect
	1075		1.86×10^{-3}	0.71	1500		
E		8.4				1500	
	875		2.51×10^{-3}	0.97	900		
F		6.2				2400	
	1100		3.82×10^{-3}	1.47	750		
G		2.0				3150	
D		10.4				0	Ocean side of transect
	1075		7.44×10^{-4}	0.28	3760		
C		9.6				3760	
	1175		2.38×10^{-3}	0.92	1280		
B		6.8				5040	
	1675		1.85×10^{-3}	0.71	2360		
A		3.7				7400	

(Appendix F). Well K3D1 was equipped with a continuous stage recorder for monitoring water levels.

The shallow aquifer system ground-water flow velocity under Bodie Island is similar to that found elsewhere on the barrier islands. Winner (1975) determined that the average flow velocity in the shallow aquifer on Cape Hatteras National Seashore is about one foot per day. The National Seashore includes the southern end of Bodie Island.

Travel times from the ground-water divide on the island to the sound are much shorter than those to the ocean (Table 3-1). In general, the distance from the ground-water divide to the sound is less than the distance from this divide to the ocean. Also, the hydraulic gradient toward the sound is generally steeper than that toward the ocean. These two factors reinforce each other to reduce travel times to the sound.

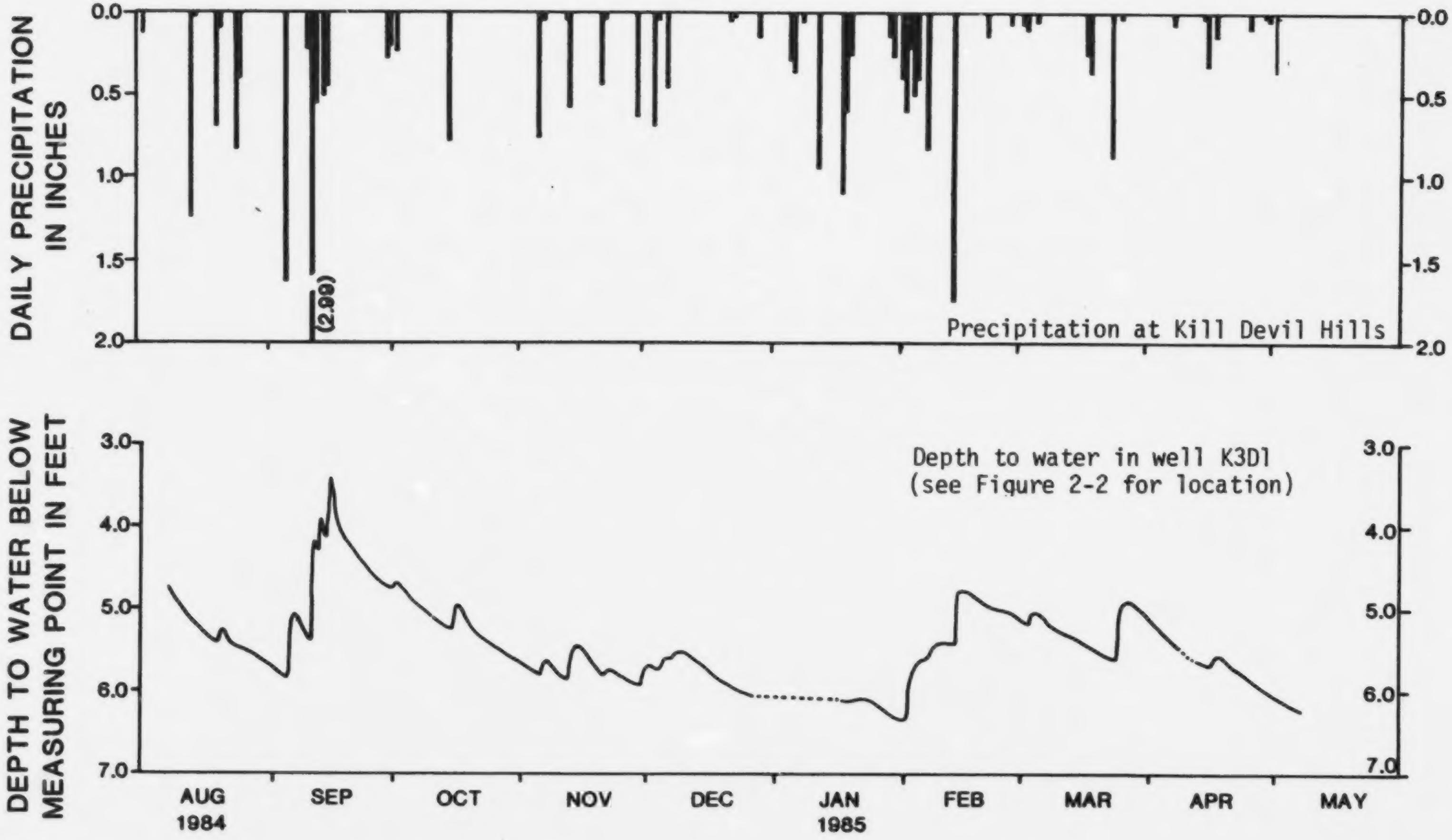
The shortest residence times occur when water enters the shallow aquifer near the ocean and sound. Flowpaths are shortest and flow velocities are greatest in these areas. The travel time to the ocean along Transect K1 is about three months for a water particle entering the shallow aquifer at well site K1A, and the travel time to the sound is about one month for a water particle entering the shallow aquifer at well site K1E. At Transect K3, the travel time to the ocean from well site K3A is about six months, whereas the travel time to the sound from well site K3G is about seven months. These travel times are representative residence times for water that enters the shallow aquifer in developed areas near the ocean and sound.

3.1.2.3 Water Levels

Ground-water levels in the shallow aquifer varied in response to recharge and discharge. Water levels would rise rapidly in response to precipitation and fall gradually at other times due to discharge. The long-term water-level recession rate due to discharge is about 0.03 ft/day at well K3D1. This rate is the same as that observed by Winner (1975) on the Cape Hatteras National Seashore. Discharge includes seepage of water to the ocean and the sound, transpiration by vegetation and evaporation. Water-level variations in well K3D1, generally reflective of recharge and discharge conditions in the Kill Devil Hills study area, are presented in Figure 3-6.

Water level measurements were made in all wells over 24-hour periods in August 1984 and February 1985 in an attempt to measure the impacts of changes in evapotranspiration on the ground-water table. Diurnal water-level fluctuations that could be attributed to evapotranspiration were not evident in these measurements. Also, no diurnal fluctuations were observed on the recorder charts from well K3D1. The scarcity of vegetation in the Kill Devil Hills study area probably accounts for the lack in diurnal water-level fluctuations during the growing season.

The influence of tidal fluctuations on water levels appears to be confined to areas adjacent to the ocean and sound. Water-level variations of 0.1 to 0.2 feet that were probably caused by tidal influences were observed in wells adjacent to the ocean and sound during



EXPLANATION

(2.99) Total rainfall for the day when the total exceeds the scale

------ Dashed line represents missing water level record

Figure 3-6. Relation between ground-water levels and precipitation in the Kill Devil Hills study area.

24-hour periods in August 1984 and again in February 1985. Water levels in the other monitoring wells at these times did not appear to be influenced by tidal fluctuations.

3.1.2.4 Net Ground-Water Recharge

Net recharge to the shallow aquifer is the difference between water gains and water losses at the water-table surface. Water gains occur as infiltration from precipitation and wastewater disposal. Water losses occur as a result of evapotranspiration. Changes in water stored in the unsaturated zone overlying the shallow aquifer influences the net recharge and must also be taken into account.

Net recharge to the water table for a given time period can be expressed in equation form as:

$$W = I_p + I_w - \Delta S - ET \qquad (2)$$

Where: W = net recharge, in inches;

I_p = infiltration from precipitation, in inches;

I_w = infiltration from wastewater disposal, in inches;

ΔS = change in soil moisture storage; in inches; and

ET = evapotranspiration, in inches.

Equation (2) represents a water budget for water gains and losses at the water-table surface. Monthly water budgets based on equation (2) are presented in Table 3-2 for each of the transects.

Precipitation is the major source for recharge to the shallow aquifer. Precipitation accounted for approximately 90, 86 and 93 percent of the recharge along Transects K1, K2 and K3, respectively. Wastewater accounted for the remainder of the recharge received along these transects.

All precipitation was assumed to infiltrate into the soil in this analysis. This assumption is reasonable as the soil is permeable and little or no runoff is observed during most rains. Also, the storm water collection system in Kill Devil Hills is minimal. Runoff generally ponds in low areas and eventually seeps into the ground or evaporates.

Monthly precipitation for the analysis was determined from daily rainfall records collected by the town of Kill Devil Hills water department. Data for June and part of July were supplemented with that collected by the National Weather Service at Manteo, located approximately eight miles southwest of Kill Devil Hills.

Wastewater disposal for the analysis was assumed to be equal to water use. Most water used by residents in Kill Devil Hills is treated on-site and disposed of by infiltration of the water into the ground.

TABLE 3-2

SUMMARY OF RECHARGE COMPUTATIONS FOR TRANSECTS IN KILL DEVIL HILLS(1)

Transect ID	Parameter	1984							1985					Totals
		June	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	
K1	I_p	0.88	7.35	3.39	7.01	1.07	2.49	1.38	5.00	3.85	2.60	1.09	3.27	39.38
	I_w	0.10	0.26	0.26	0.17	0.12	0.12	0.12	0.06	0.06	0.04	0.07	0.17	1.55
	ΔS	-0.80	0.80	-0.80	0.80	-0.80	0.80	0	0	0	0	-0.80	0	-0.80
	ET	1.68	5.82	4.19	3.87	1.87	1.19	1.06	0.12	0.27	1.22	1.89	3.27	26.45
	W	0.10	0.99	0.26	2.51	0.12	0.62	0.44	4.94	3.64	1.42	0.07	0.17	15.28
K2	I_p	0.88	7.35	3.39	7.01	1.07	2.49	1.38	5.00	3.85	2.60	1.09	3.27	39.38
	I_w	0.12	0.31	0.31	0.20	0.19	0.19	0.19	0.13	0.13	0.05	0.10	0.24	2.16
	ΔS	-0.80	0.80	-0.80	0.80	-0.80	0.80	0	0	0	0	-0.80	0	-0.80
	ET	1.68	5.82	4.19	3.87	1.87	1.19	1.06	0.12	0.27	1.22	1.89	3.27	26.45
	W	0.12	1.04	0.31	2.54	0.19	0.69	0.51	5.01	3.71	1.43	0.10	0.24	15.89
K3	I_p	0.88	7.35	3.39	7.01	1.07	2.49	1.38	5.00	3.85	2.60	1.09	3.27	39.38
	I_w	0.04	0.20	0.20	0.13	0.08	0.08	0.08	0.02	0.02	0.03	0.06	0.14	1.08
	ΔS	-0.80	0.80	-0.80	0.80	-0.80	0.80	0	0	0	0	-0.80	0	-0.80
	ET	1.68	5.82	4.19	3.87	1.87	1.19	1.06	0.12	0.27	1.22	1.89	3.27	26.45
	W	0.04	0.93	0.20	2.47	0.08	0.58	0.40	4.90	3.60	1.41	0.06	0.14	14.81

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(1) All values are reported in inches.

Monthly wastewater disposal along each transect was estimated from the quarterly water use records for residents along the transects. The ratio of monthly to quarterly water use, needed to distribute water use on a monthly basis, was assumed to be the same as that observed at Atlantic Beach.

Monthly soil moisture changes and monthly evapotranspiration used in the analysis were computed using methods outlined by the EPA (Fenn et al., 1975). These methods are described in Appendix G.

3.1.2.5 Water Quality

Ground-water samples were taken periodically for the analysis of selected parameters (Table 3-3). Water samples were collected in July 1984, October 1984, January 1985 and April 1985 along Transect K2, the designated high population density transect, in July 1984 and January 1985 along Transect K1, the designated medium population density transect, and in January 1985 along the designated low population density transect, Transect K3.

Water samples were collected with two objectives in mind. One objective was to define the relationship between saltwater and freshwater in the shallow aquifer. The second objective was to define the current impact of wastewater disposal on the quality of water in the shallow aquifer.

3.1.2.5.1 Relationship Between Freshwater and Saltwater

Measured chemical properties of the ground water used to aid in defining saltwater intrusion into the shallow aquifer included sodium concentration, chloride concentration, total dissolved solids concentration and specific conductance. Sodium and chloride are the major constituents in saltwater. Total dissolved solids measures all solids in solution in the water, including sodium and chloride. Specific conductance measures the ability of water to conduct an electrical current and generally increases with an increase in total dissolved solids content in the water.

Elevated total dissolved solids concentrations had a strong correlation with elevated sodium and chloride concentrations in water from the shallow aquifer and is a good indicator of saltwater intrusion into the aquifer. The total dissolved solids content in the water was used to determine the presence of saltwater and freshwater in the shallow aquifer.

Elevated specific conductances also correlated well with increased sodium and chloride concentrations in water from the aquifer.

Water has been classified based on the total dissolved solids content in the water (Fetter, 1980). Water with a total dissolved solids content less than 1,000 milligrams per liter (mg/l) is considered to be freshwater. Water with a total dissolved solids content between 1,000 and 10,000 mg/l is considered to be brackish, and water with a total dissolved solids content greater than 10,000 mg/l is considered to be

TABLE 3-3

SUMMARY OF GROUND-WATER QUALITY ANALYSES FOR KILL DEVIL HILLS$^{(1)}$

Well ID	Sampling date	Sodium	Chloride	Total dissolved solids	Ammonia (mg/l as N)	Nitrate plus nitrite (mg/l as N)	Alkalinity (mg/l as $CaCO_3$)	Hardness (mg/l as $CaCO_3$)	MBAS (mg/l)	Orthophosphate (mg/l as P)	Temperature °C	Specific conductance (µmhos/cm)	pH (s.u.)	Fecal coliform (colonies per 100/ml)
Kill Devil Hills Transect K1														
K1A1	9Jul84	31	40	558	<0.01	0.59	104	210	<0.02	0.25	22	500	7.56	<1
	16Jan85	19	17	316	0.02	1.31	158	198	0.06	0.16	16	415	7.18	<1
K1A2	9Jul84	247	218	806	<0.01	<0.05	156	124	0.05	0.15	22	1400	7.96	<1
	16Jan85	85	170	534	0.02	<0.05	141	202	0.04	0.11	20	850	7.48	<1
K1A3	9Jul84	448	890	1918	1.38	<0.05	177	44	<0.02	0.25	22	3150	7.75	<1
	16Jan85	344	995	2388	2.17	<0.05	192	602	0.02	0.28	22	3300	7.52	<1
K1B1	11Jul84	14	15	452	0.05	0.46	31	32	<0.02	0.27	24	185	6.10	<1
	16Jan85	22	13	228	<0.01	1.82	58	66	0.06	0.27	14	140	6.86	<1
K1C1	9Jul84	20	27	164	<0.01	<0.05	22	50	0.06	0.03	22	250	6.20	<1
	16Jan85	19	16	104	<0.01	<0.05	22	24	0.02	0.06	14	95	6.07	<1
K1C4	9Jul84	223	480	1104	0.52	<0.05	98	318	<0.02	0.13	22	370	7.89	<1
	16Jan85	22	32	254	0.30	<0.05	160	140	0.01	0.15	18	410	6.92	<1
K1C5	9Jul84	28	26	226	0.31	<0.05	88	130	<0.02	0.03	22	650	7.78	<1
	16Jan85	173	369	1118	1.00	<0.05	113	290	<0.02	0.20	17	1630	7.54	<1
K1D1	11Jul84	8	10	172	0.81	0.77	20	34	<0.02	0.15	24	145	6.46	<1
	16Jan85	8	6	92	<0.01	0.11	18	18	0.02	0.12	14	53	6.64	<1
K1E1	11Jul84	42	51	330	1.35	1.11	187	148	<0.02	1.26	24	580	6.54	<1
	16Jan85	37	57	234	2.31	<0.05	121	112	0.02	0.09	13	320	6.50	<1
K1E2	11Jul84	11	30	135	0.51	<0.05	73	70	<0.02	0.58	22	210	8.22	<1
	16Jan85	11	14	122	0.38	<0.05	76	62	0.02	0.02	18	165	7.48	<1
K1E3	11Jul84	101	123	446	2.05	1.04	153	62	0.12	1.26	22	700	8.39	<1
	16Jan85	86	99	380	2.20	<0.05	185	76	0.03	0.15	19	650	7.89	<1

TABLE 3-3
(continued)
SUMMARY OF GROUND-WATER QUALITY ANALYSES FOR KILL DEVIL HILLS

Well ID	Sampling date	Sodium	Chloride	Total dissolved solids	Ammonia (mg/l as N)	Nitrate plus nitrite (mg/l as N)	Alkalinity (mg/l as $CaCO_3$)	Hardness (mg/l as $CaCO_3$)	MBAS (mg/l)	Orthophosphate (mg/l as P)	Temperature °C	Specific conductance (µmhos/cm)	pH (s.u.)	Fecal coliform (colonies per 100/ml)
Kill Devil Hills (cont'd) Transect K2														
K2A1	11Jul84	40	46	235	<0.01	0.36	92	86	0.21	0.53	22	321	8.12	<1
	21Oct84	47	680*	576	0.27	0.60	104	508*	0.13	0.16	19	3200	7.10	<1
	17Jan85	63	92	338	<0.01	<0.05	124	122	0.53	0.18	16	455	7.24	<1
	09Apr85	152	250	790	1.13	3.06	125	263	0.09	0.19	17	1040	7.95	<1
K2A2	11Jul84	619	1230	2872	<0.01	0.43	128	648	0.12	0.19	21	4110	7.66	<1
	21Oct84	552	913	1134	0.41	0.23	148	580	0.10	0.02	16	3200	7.45	<1
	17Jan85	84	2317	5938	1.11	0.65	140	1224	<0.02	0.04	25	7000	7.38	<1
	09Apr85	346	3087	6768	0.14	1.20	131	1361	0.07	0.03	17	9100	7.56	<1
K2A3	11Jul84	87	126	377	0.06	<0.05	88	70	0.15	0.50	22	580	7.77	<1
	21Oct84	78	94	494	0.13	<0.05	105	82	0.08	0.45	16	480	7.70	<1
	17Jan85	74	107	438	0.08	<0.05	107	90	0.02	0.46	18	600	7.54	<1
	09Apr85	80	107	322	<0.01	0.96	104	94	0.04	0.41	16	590	7.65	<1
K2B1	11Jul84	17	21	162	<0.01	0.47	64	70	0.26	1.51	24	240	6.73	<1
	21Oct84	11	15	186	0.02	0.52	61	74	0.08	0.04	19	210	6.70	<1
	17Jan85	12	17	178	0.02	0.50	73	84	<0.02	0.07	15	187	6.73	<1
	09Apr85	12	22	152	0.14	0.16	80	102	0.05	0.07	16	232	6.60	<1
K2B2	11Jul84	21	29	241	0.07	<0.05	109	130	0.30	0.39	22	350	7.63	<1
	21Oct84	22	28	300	0.10	<0.05	121	130	0.21	0.38	16	310	7.74	<1
	17Jan85	23	29	264	0.47	<0.05	135	122	0.03	0.37	18	305	7.50	<1
	09Apr85	35	31	228	0.46	0.67	154	143	0.07	0.37	18	358	7.77	<1
K2B3	11Jul84	121	220	587	0.49	<0.05	171	170	0.10	0.29	23	1050	7.44	<1
	21Oct84	140	184	568	0.61	<0.05	202	178	0.21	0.26	16	950	7.56	<1
	17Jan85	175	192	574	0.52	<0.05	204	164	<0.02	0.26	19	950	7.56	<1
	09Apr85	59	169	519	0.85	0.17	201	162	0.10	0.30	18	900	7.62	<1
K2C1	12Jul84	11	25	172	0.49	<0.05	24	32	0.27	0.67	25	211	5.73	<1
	21Oct84	9	20	182	0.80	<0.05	23	30	0.12	0.73	19	125	6.03	<1
	17Jan85	14	14	168	0.27	<0.05	32	250	<0.02	0.99	15	110	5.92	<1
	09Apr85	13	19	114	0.42	0.06	46	41	0.07	0.59	18	151	5.42	<1
K2C2	12Jul84	16	20	354	0.33	<0.05	203	236	0.25	0.19	24	459	6.39	<1
	21Oct84	16	19	362	0.55	<0.05	236	210	<0.02	0.34	16	430	6.96	<1
	17Jan85	13	19	234	0.39	<0.05	152	176	<0.02	0.32	8	440	6.75	<1
	09Apr85	15	18	287	0.55	<0.05	225	223	0.08	0.37	19	422	7.00	<1
K2C3	12Jul84	64	61	390	0.17	<0.05	198	174	0.11	0.27	23	230	6.82	<1
	21Oct84	43	35	370	0.42	<0.05	255	195	<0.02	0.37	16	480	7.16	<1
	17Jan85	37	45	358	0.09	<0.05	259	182	<0.02	0.46	18	490	6.71	<1
	09Apr85	39	30	300	0.15	<0.05	213	175	0.05	0.63	18	435	6.55	<1
K2C4	12Jul84	87	78	404	0.14	<0.05	183	116	0.06	0.13	22	600	6.93	<1
	21Oct84	71	64	412	0.22	<0.05	220	137	0.07	0.35	16	480	7.46	<1
	17Jan85	52	62	362	0.54	<0.05	223	140	0.06	0.31	18	495	7.22	<1
	09Apr85	68	60	356	<0.01	0.80	210	137	0.09	0.34	18	580	7.52	<1

TABLE 3-3
(continued)
SUMMARY OF GROUND-WATER QUALITY ANALYSES FOR KILL DEVIL HILLS

Well ID	Sampling date	Sodium	Chloride	Total dissolved solids	Ammonia (mg/l as N)	Nitrate plus nitrite (mg/l as N)	Alkalinity (mg/l as $CaCO_3$)	Hardness (mg/l as $CaCO_3$)	MBAS (mg/l)	Orthophosphate (mg/l as P)	Temperature °C	Specific conductance (µmhos/cm)	pH (s.u.)	Fecal coliform (colonies per 100/ml)
Kill Devil Hills (cont'd)														
Transect K2														
K2D1	12Jul84	29	22	156	0.20	<0.05	33	36	0.07	<0.01	23	326	5.90	<1
	21Oct84	24	14	162	0.02	0.83	41	22	0.50	0.16	19	185	6.53	8
	17Jan85	26	30	182	0.11	1.52	58	52	0.02	0.14	15	245	6.67	<1
	09Apr85	31	27	178	1.90	1.70	61	56	0.07	<0.01	17	289	6.32	<1
K2D2	12Jul84	13	31	204	1.12	<0.05	106	140	<0.02	0.43	22	311	6.01	<1
	21Oct84	14	27	266	1.64	0.05	127	134	0.16	0.50	15	310	6.99	<1
	17Jan85	14	27	220	0.34	0.78	114	124	0.02	0.31	19	310	6.99	<1
	09Apr85	18	26	215	0.28	0.08	122	139	<0.02	0.61	18	330	6.95	<1
K2D3	12Jul84	25	33	240	0.32	<0.05	109	124	<0.02	0.08	22	285	6.28	<1
	21Oct84	22	37	258	0.60	<0.05	148	145	0.24	0.28	15	340	7.39	<1
	17Jan85	14	36	238	0.31	0.26	137	144	0.06	0.21	18	350	7.00	<1
	09Apr85	26	37	240	0.99	0.91	147	147	<0.02	0.31	18	369	7.44	<1
K2E1	11Jul84	11	187*	175	0.71	0.42	32	38	0.13	0.53	23	188	6.35	<1
	21Oct84	15	27	204	0.88	0.05	18	42	0.10	0.54	18	185	6.22	<1
	17Jan85	13	23	168	0.90	<0.05	35	100	<0.02	0.86	13	150	5.98	<1
	09Apr85	16	22	157	0.34	0.23	85	56	<0.02	0.50	17	198	6.05	<1
K2E2	11Jul84	11	12	183	0.18	<0.05	110	124	0.05	0.43	22	275	8.02	63
	21Oct84	11	13	196	0.28	<0.05	126	116	0.23	0.40	15	230	7.88	<1
	17Jan85	9	12	108	0.04	0.07	107	92	<0.02	0.50	18	200	6.91	<1
	09Apr85	16	12	161	0.41	0.30	103	94	<0.02	0.43	17	210	8.14	<1
K2E3	11Jul84	92	198	532	0.20	<0.05	114	130	0.12	0.29	22	850	7.42	<1
	21Oct84	53	34	440	0.22	<0.05	131	165	<0.02	0.30	15	700	7.47	<1
	17Jan85	57	158	390	0.23	<0.05	133	170	<0.02	0.30	18	750	7.42	<1
	09Apr85	80	164	520	0.42	0.09	127	192	<0.02	0.26	17	760	7.49	<1
Transect K3														
K3A1	16Jan85	10	16	274	<0.01	0.76	92	124	0.02	0.52	14	210	8.15	<1
K3A2	16Jan85	12	17	254	0.12	<0.05	117	108	0.02	0.36	19	210	7.62	<1
K3A2B	16Jan85	44	61	266	1.08	<0.05	138	78	<0.02	0.18	19	355	7.67	<1
K3A3B	16Jan85	30	35	212	1.98	<0.05	183	112	<0.02	0.24	19	330	7.56	<1

TABLE 3-3
(continued)
SUMMARY OF GROUND-WATER QUALITY ANALYSES FOR KILL DEVIL HILLS

Well ID	Sampling date	Sodium	Chloride	Total dissolved solids	Ammonia (mg/l as N)	Nitrate plus nitrite (mg/l as N)	Alkalinity (mg/l as $CaCO_3$)	Hardness (mg/l as $CaCO_3$)	MBAS (mg/l)	Orthophosphate (mg/l as P)	Temperature °C	Specific conductance (µmhos/cm)	pH (s.u.)	Fecal coliform (colonies per 100/ml)
Kill Devil Hills (cont'd) Transect K3														
K3B1	16Jan85	9	13	56	4.38	<0.05	18	80	0.03	0.14	14	75	5.58	<1
K3C1	16Jan85	11	13	150	6.88	<0.05	31	44	<0.02	0.54	14	70	6.51	<1
K3D1	16Jan85	11	14	28	1.72	<0.05	5	28	<0.02	0.54	18	110	7.88	<1
K3D2	16Jan85	21	50	188	2.87	<0.05	38	56	<0.02	0.45	14	260	7.17	<1
K3D3B	16Jan85	62	148	366	1.28	0.11	148	130	<0.02	0.47	18	750	8.24	<1
K3E1	16Jan85	8	7	18	1.26	<0.05	33	52	<0.02	1.02	15	65	8.34	<1
K3F1	16Jan85	60	11	102	1.13	<0.05	7	20	<0.02	0.09	14	42	7.63	<1
K3G1	16Jan85	21	27	296	2.62	<0.05	174	158	<0.02	1.14	14	300	6.08	<1
K3G2	16Jan85	7	10	230	2.02	<0.05	93	19[illegible]	<0.02	1.04	17	160	6.84	<1
K3G3	16Jan85	4	255	670	2.57	<0.05	109	160	<0.02	0.87	18	1000	7.41	<1

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(1) All analyses are in milligrams per liter (mg/l) unless otherwise noted.

*Results verified.

saline. Saltwater from the ocean typically has a total dissolved solids content of about 35,000 mg/l.

Freshwater generally exists within the shallow aquifer at Kill Devil Hills. The total dissolved solids content of the water was less than 1,000 mg/l at all well sites except K1A, K1C and K2A (Table 3-3).

Variations in the total dissolved solids content of water in the shallow aquifer are apparent (Figure 3-7). Water with a total dissolved solids content of about 200 mg/l occurs along the water-table surface at Transect K2. The total dissolved solids content in the water increases with depth and is generally 400 to 600 mg/l at the aquifer base. Elevated levels of total dissolved solids occur near the ocean where freshwater and saltwater begin to come into contact.

3.1.2.5.2 Effects of Wastewater Disposal

Measured chemical properties of the ground water used to aid in defining the effects of wastewater disposal to the shallow aquifer included nitrate plus nitrite concentration (nitrate/nitrite), ammonia concentration, orthophosphate concentration, methylene blue active substances (MBAS) concentration and fecal coliform concentration. Nitrate, nitrite, ammonia and orthophosphate are common nutrients present in wastewater. MBAS are substances used in detergents and that do not occur naturally in the environment. Fecal coliform are a group of bacteria which come from the intestines of mammals and may be found in wastewater and sometimes storm water runoff.

Nitrate/nitrite and ammonia, reported in mg/l as nitrogen (N), were detected in ground water along all three transects (Table 3-3). Nitrate/nitrite levels are generally higher at the water table surface while ammonia levels are generally higher below the water table along Transects K1 and K2. Relatively high levels of ammonia and low levels of nitrate/nitrite were measured at most monitoring wells along Transect K3. Variations in nitrate/nitrite and ammonia concentrations along Transect K2 are shown in Figures 3-8 and 3-9, respectively.

Nitrate, nitrite and ammonia are contaminants which are commonly found in ground water. The presence of these constituents in the shallow ground water could, therefore, be indicative of the impact of wastewater disposal. The highest observed levels of nitrate/nitrite and ammonia were 3.06 mg/l and 6.88 mg/l, respectively. The drinking water standard for nitrates is 10 mg/l as nitrogen. There are no drinking water standards for ammonia.

Orthophosphates, reported in mg/l as phosphorus (P), generally decreased in concentration with depth, but exceptions to this were not uncommon (Table 3-3). Variations in the orthophosphate concentration along Transect K2 are shown in Figure 3-10.

The presence of phosphorus compounds in the ground water is probably due to wastewater disposal. The usual sources for phosphorus are organic waste products and phosphate detergent residues. The highest observed level of orthophosphate was 1.51 mg/l. There are no drinking water standards for orthophosphates.

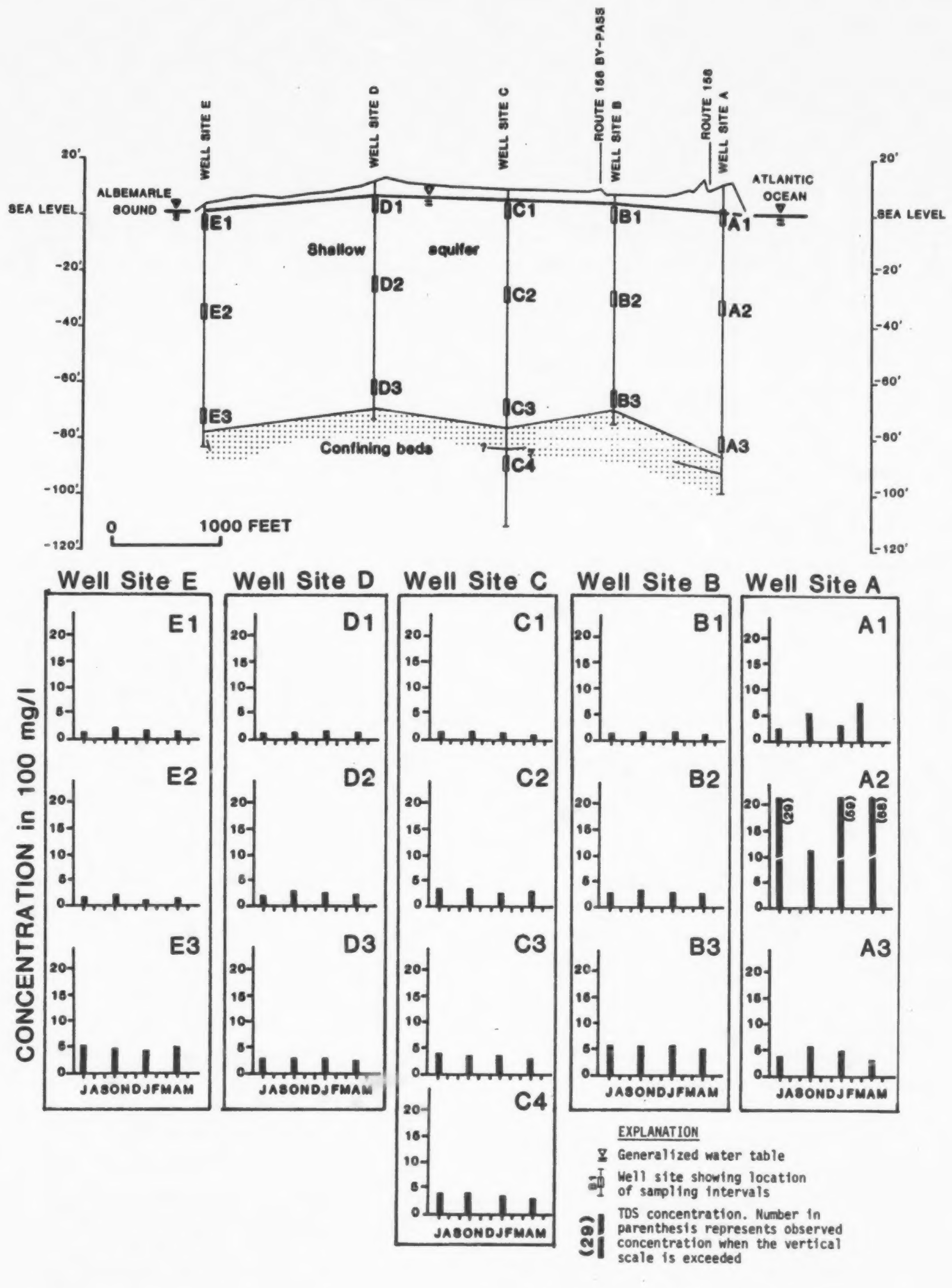


Figure 3-7. Variation in total dissolved solids concentration along Transect K2.

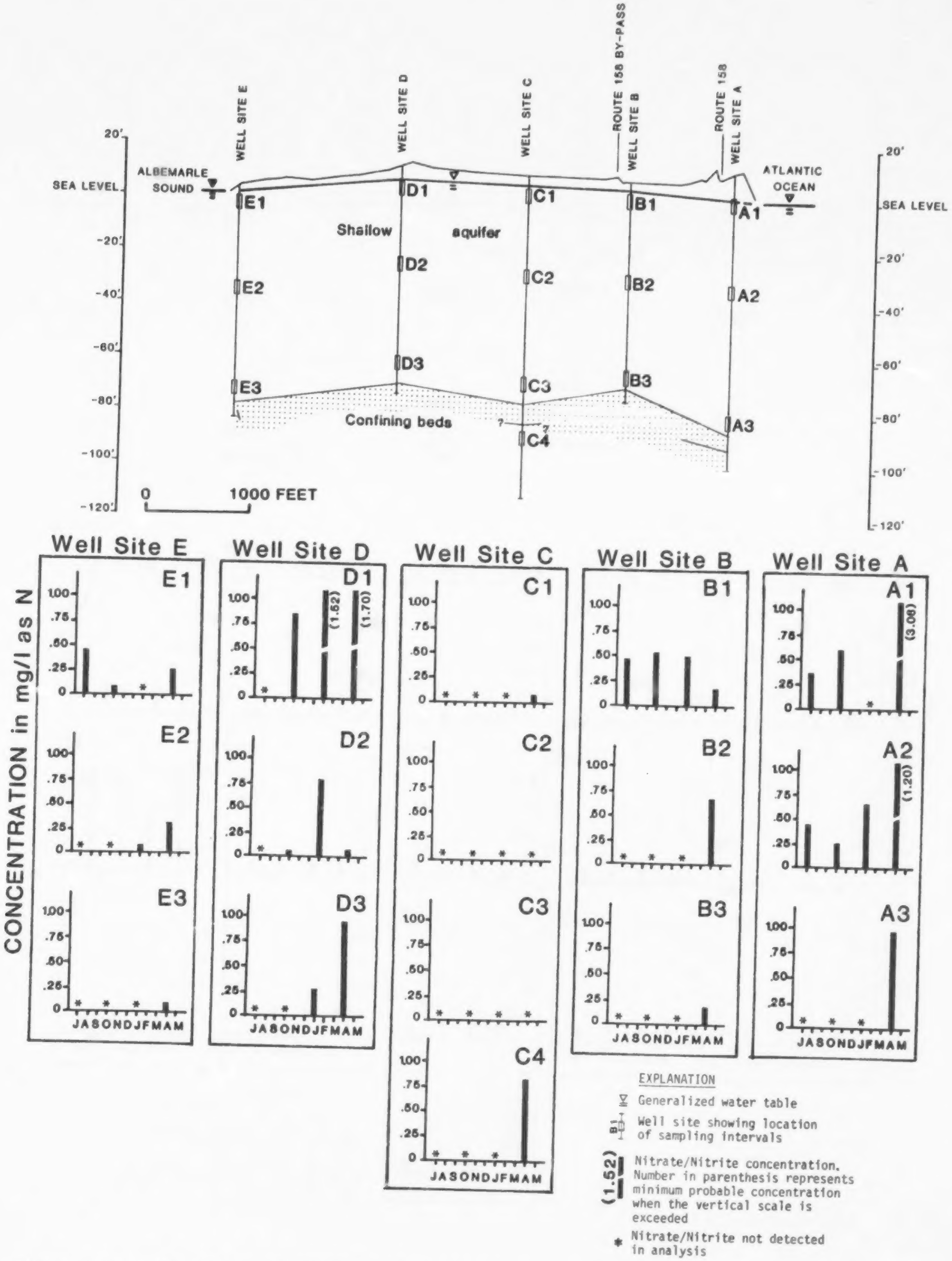


Figure 3-8. Variation in nitrate plus nitrite concentration along Transect K2.

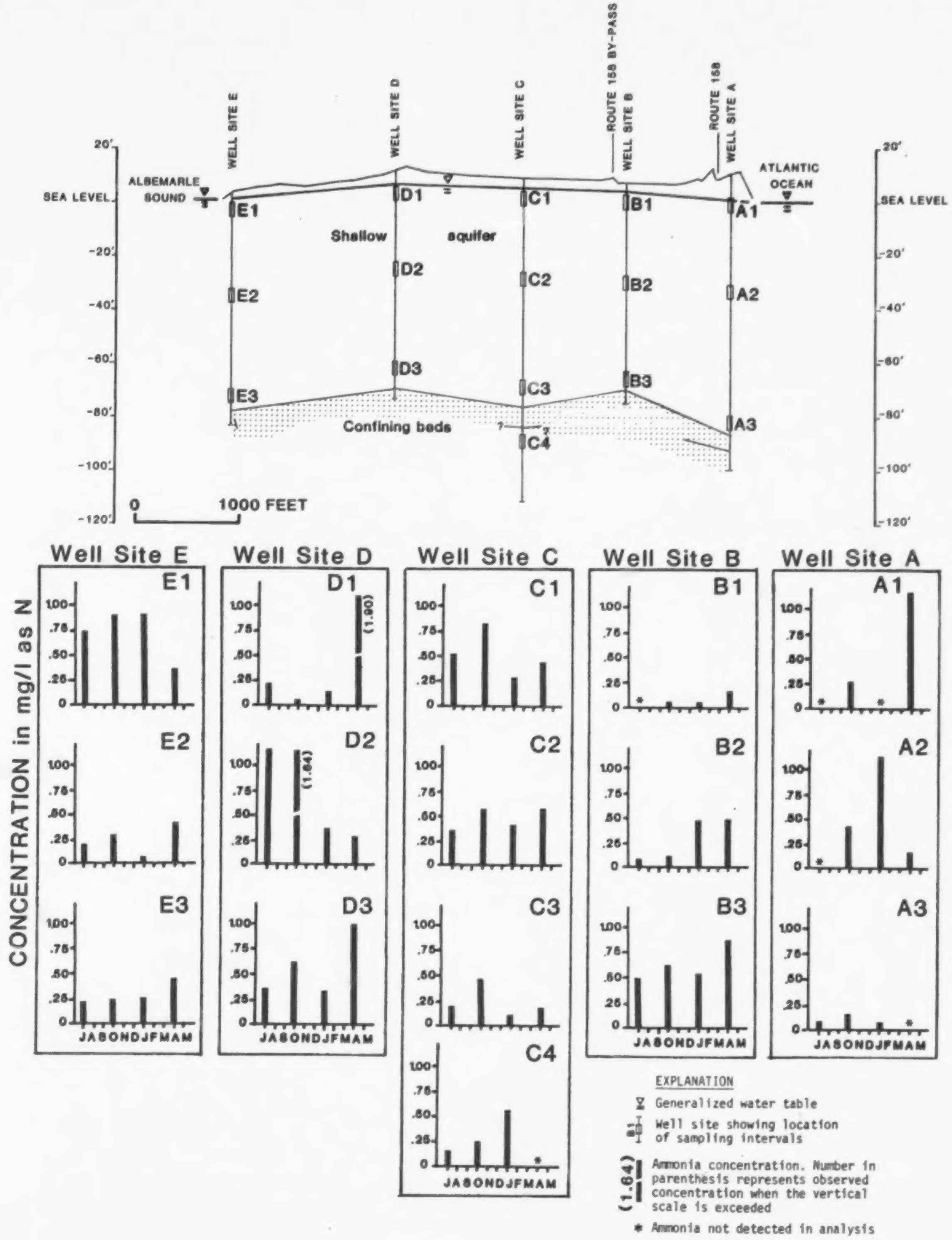


Figure 3-9. Variation in ammonia concentration along Transect K2.

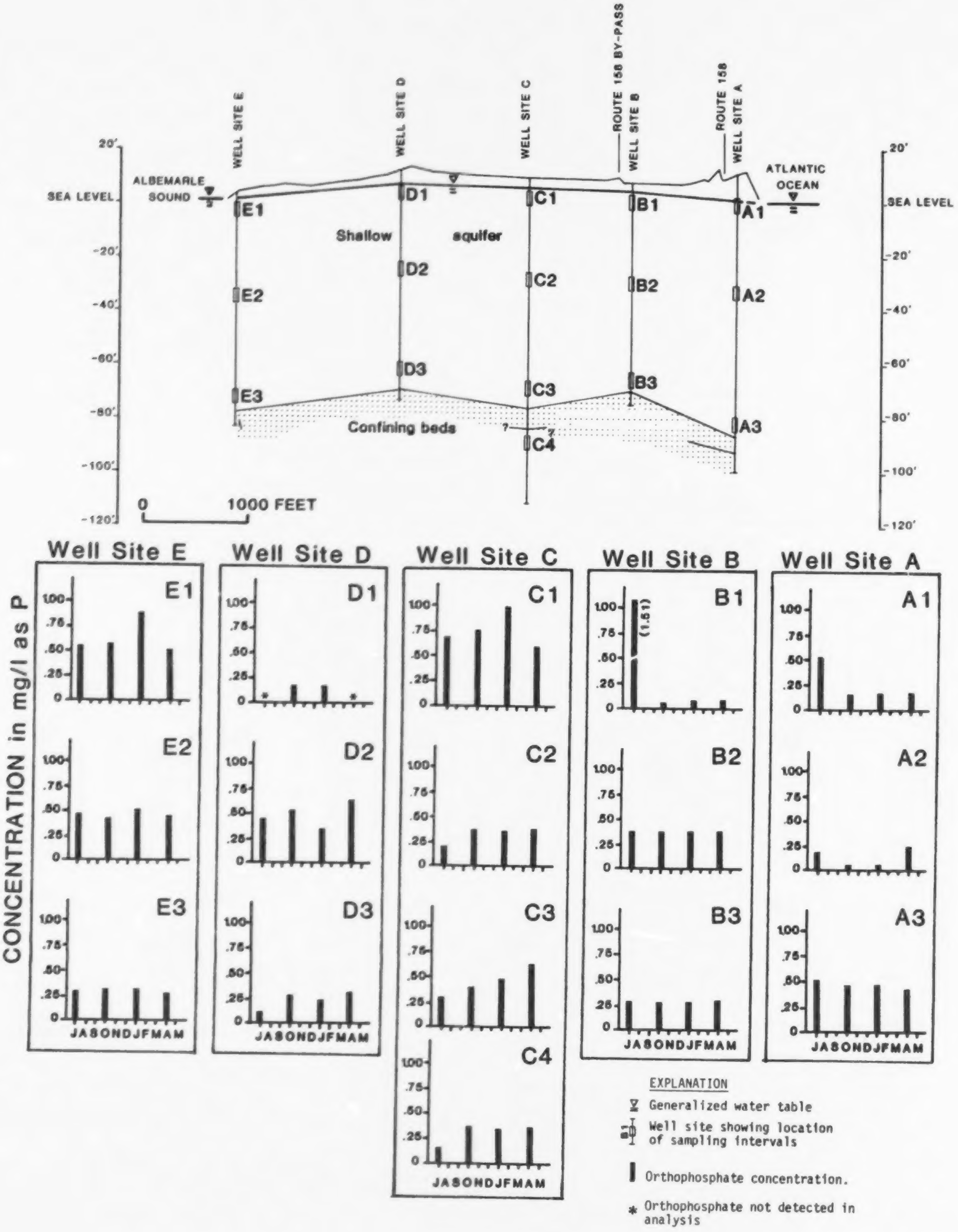


Figure 3-10. Variation in orthophosphate concentration along Transect K2.

MBAS were detected at all wells along Transect K2 during the course of the study (Figure 3-11). This observation indicates that wastewater disposal has penetrated the entire thickness of the shallow aquifer and has also penetrated the confining beds underlying the aquifer in the vicinity of the transect. Higher levels of MBAS were generally detected at the water-table surface whereas lower levels were generally detected with depth. The highest observed level of MBAS was 0.53 mg/l. This value was noted in water from well K2A1 in January 1985 and is the only sample in which MBAS exceeded the recommended secondary drinking water standard of 0.50 mg/l.

Very minor concentrations of MBAS were detected in water along Transect K1 and essentially no MBAS were present in water along Transect K3 (Table 3-3).

Fecal coliform were found in only two of the 100 ground-water samples collected in Kill Devil Hills. Fecal coliform levels of eight colonies per 100 milliliters of sample (col/100 ml) were detected at well K2D1 in October 1984. The fecal coliform count in water from well K2E2 was 63 col/100 ml in July 1984 (Table 3-3). Fecal coliform were not detected in water samples taken from these wells at other times of the year. Also, fecal coliform were never detected in water samples from the other monitoring wells. Fecal coliform are an indicator parameter useful for detecting the presence of domestic wastewater in the ground water.

Alkalinity and hardness of the ground water were measured as overall indicators for water quality (Table 3-3). Alkalinity is a measure of the carbonate and bicarbonate ions in the water, with maximum levels of approximately 400 mg/l as calcium carbonate ($CaCO_3$) considered to represent no health problem. Hardness is a measure of the amount of calcium, magnesium and iron in the water.

Alkalinity generally increased with depth in the shallow aquifer. The alkalinity of the water was typically less than 100 mg/l as $CaCO_3$ at the water-table surface and between 100 and 250 mg/l as $CaCO_3$ below the water table surface. The alkalinity of the water is in the range of that generally found in ground waters.

The hardness of the water also increased with depth in the aquifer (Table 3-3). Hardness was generally less than 100 mg/l at the water table and between 100 and 300 mg/l elsewhere in the aquifer. Water is generally considered to be hard water when the hardness exceeds 150 mg/l.

The water hardness at well sites K1A and K2A near the ocean appears to be anomalous. These anomalies are probably associated with increases in calcium and magnesium associated with saltwater.

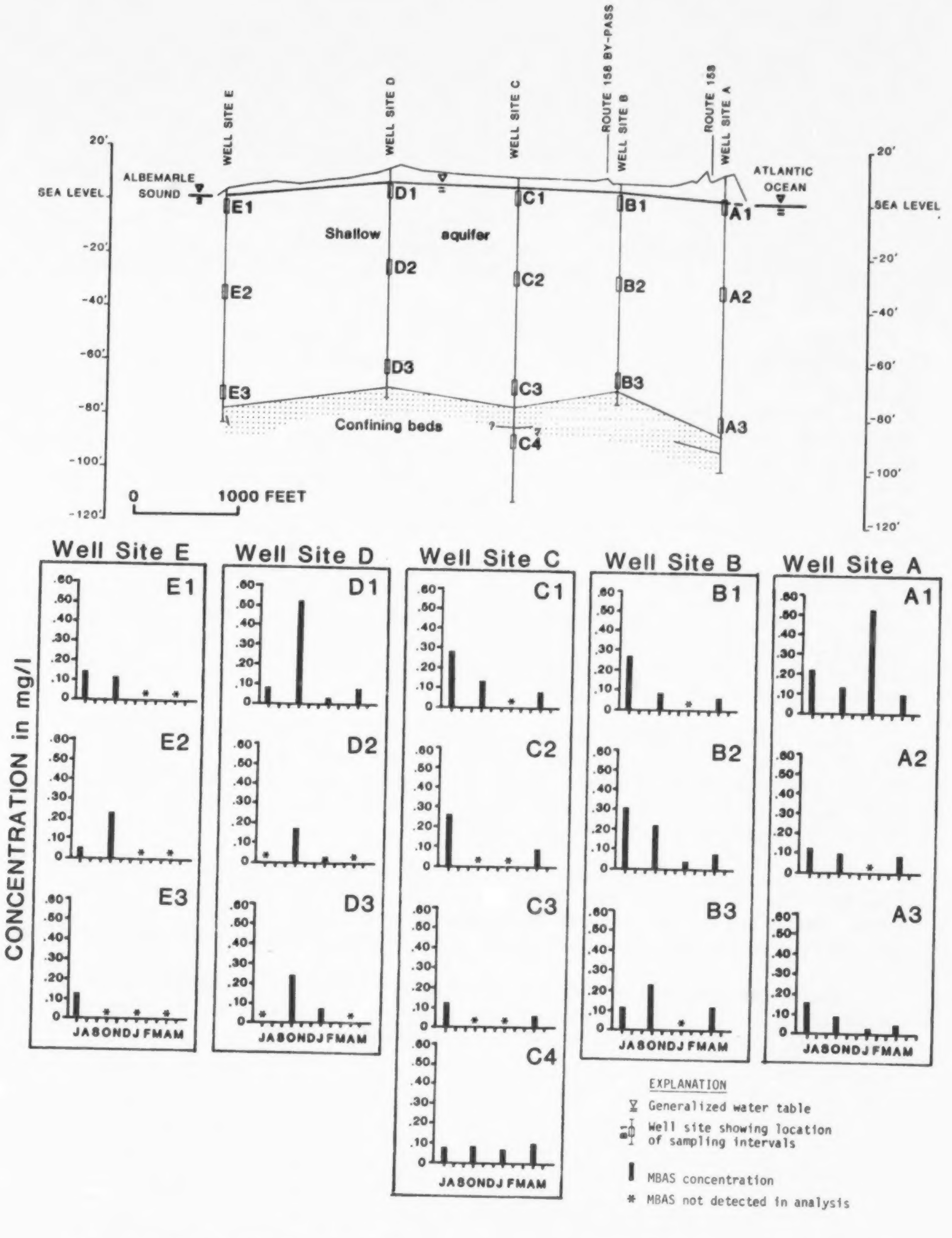


Figure 3-11. Variation in MBAS concentration along Transect K2.

3.1.3 Summary of Hydrogeologic Setting for the Kill Devil Hills Study Area

The hydrogeology at Kill Devil Hills was studied to identify the movement of ground water in the shallow aquifer underlying Bodie Island, to identify the components of recharge to the aquifer and their magnitude, and to identify the existing quality of ground water underlying the island. The results of this study can be summarized as follows:

- Bodie Island is underlain by three aquifers that are known to contain freshwater.
- The shallow aquifer, consisting of fine to medium sand, extends downward from land surface to depths of 65 to 100 feet and is separated from the deeper aquifers by beds of silt and clay.
- Ground-water movement in the shallow aquifer is generally away from the central part of Bodie Island toward discharge points in the ocean and the sound. The ground-water flow velocity averages about 0.7 feet per day.
- Tidal fluctuations have little or no influence on ground-water levels outside the immediate vicinity of the ocean and the sound.
- Precipitation accounted for 86 to 93 percent of the recharge to the shallow aquifer and wastewater accounted for the remainder.
- Freshwater exists throughout most of the shallow aquifer.
- Disposal of wastewater into the shallow aquifer has had a minor impact on ground-water quality.

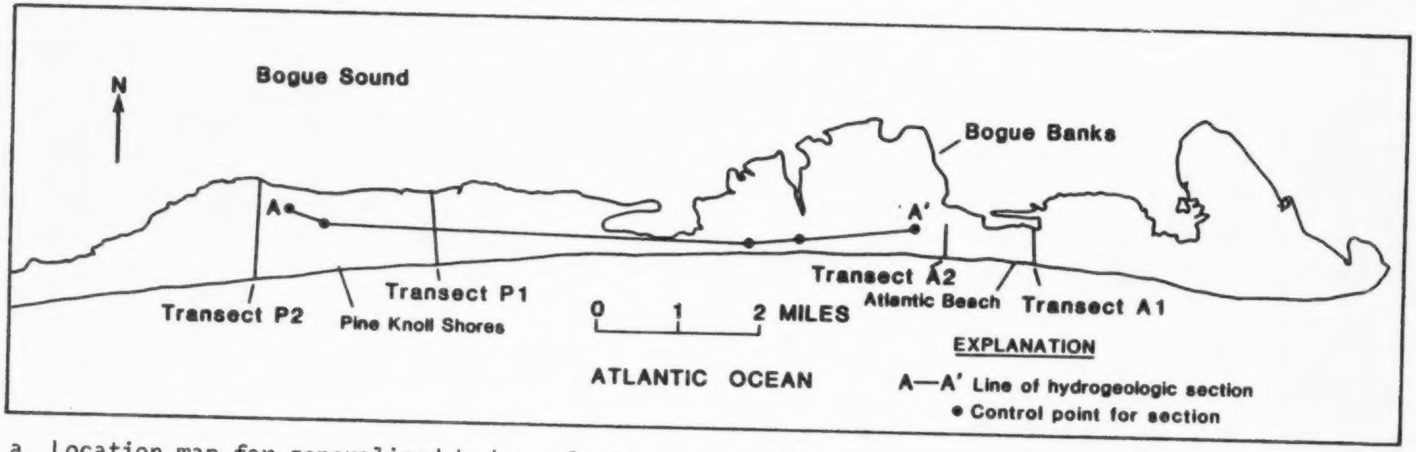
3.2 Hydrogeology of the Atlantic Beach/Pine Knoll Shores Study Area

3.2.1 General Hydrogeology

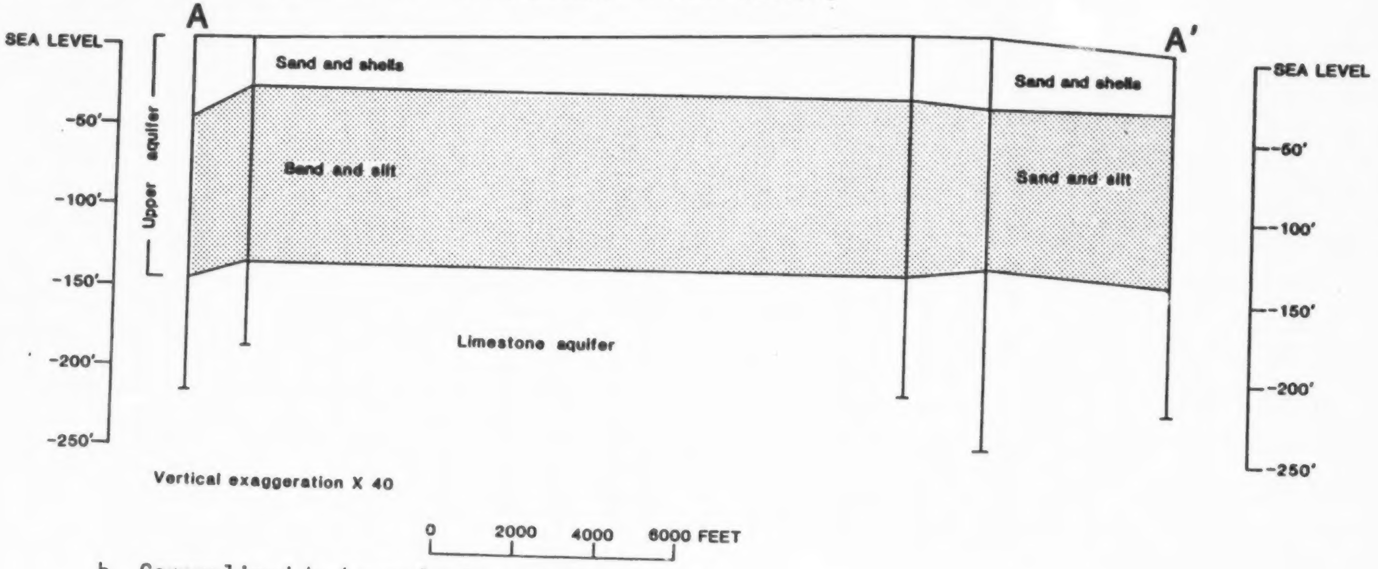
The ground-water system in northeast North Carolina has been grouped into three major aquifers: an upper aquifer, an intermediate limestone aquifer, and a lower aquifer (Wilder et al., 1978). The upper aquifer is primarily sands interbedded with shells, sandy silts and clays, and is about 150 feet thick in the study area. The limestone aquifer underlies the upper aquifer and is probably 1000 feet thick in the area. The lower aquifer lies beneath the limestone aquifer and is about 3500 feet thick in the area.

The upper aquifer on Bogue Banks is composed of a shallow unconfined aquifer underlain by confining beds. A generalized hydrogeologic cross-section along the portion of Bogue Banks that includes Atlantic Beach and Pine Knoll Shores is shown in Figure 3-12.

The upper aquifer and at least the upper portion of the limestone aquifer contain freshwater while the lower aquifer does not contain freshwater in the study area.


N
Bogue Sound
Bogue Banks
A
A'
Transect P2
Pine Knoll Shores
Transect P1
0
1
2 MILES
Transect A2
Atlantic Beach
Transect A1
ATLANTIC OCEAN
EXPLANATION
A—A' Line of hydrogeologic section
● Control point for section

a. Location map for generalized hydrogeologic cross-section.


A
A'
SEA LEVEL
-50'
-100'
-150'
-200'
-250'
Upper aquifer
Sand and shells
Sand and silt
Sand and shells
Sand and silt
Limestone aquifer
SEA LEVEL
-50'
-100'
-150'
-200'
-250'
Vertical exaggeration X 40
0
2000
4000
6000 FEET

b. Generalized hydrogeologic cross-section.

Figure 3-12. Generalized hydrogeologic cross-section for Bogue Banks.

3.2.2 Hydrogeology of the Shallow Aquifer

The shallow aquifer was studied for this report. This aquifer is the one most impacted by the use of on-site systems for the treatment and disposal of wastewater. Data collected from the wells drilled along Transects A1, A2, P1 and P2 (see Figure 3-12) formed the basis for the study.

3.2.2.1 Geologic Setting

The shallow aquifer consists of fine to medium sands with lenses of silty sands occurring in places. Clays, silts and silty fine sands which occur between 25 and 65 feet below land surface form the base of the aquifer. Geologic cross-sections showing the nature of the shallow aquifer in the Atlantic Beach/Pine Knoll Shores study area are presented in Figures 3-13 and 3-14.

The lithology of the shallow aquifer varies between Atlantic Beach and Pine Knoll Shores. In Atlantic Beach, the aquifer is generally composed of fine sand with lenses of silty fine sand. In Pine Knoll Shores, the aquifer is generally composed of fine to medium sands with occurrences of organic silt and peat near land surface. The near-surface organic material partially confines the water in areas where the material is present.

3.2.2.2 Ground-Water Occurrence and Movement

Ground water is present in the pore spaces of the unconsolidated saturated deposits that underlie Bogue Banks. The intergranular pore spaces in the sands serve as the storage space for water in the shallow aquifer and as pathways for water movement. The pore spaces in the silt and clay confining beds also serve to store water. However, these pore spaces are extremely small, making movement of water through those deposits difficult.

Ground water is also present in the limestone that underlies the unconsolidated deposits. Interconnected joints, fractures and solution openings in the limestone store and transmit water freely.

Ground-water movement is generally away from the central part of Bogue Banks toward discharge points in the ocean and the sound (Figures 3-15 through 3-18). These flow directions were defined from the distribution of freshwater heads in the aquifer, generally as measured by water levels in the monitoring wells. There were no significant differences in density of the ground water in the monitoring wells except at wells A2A4 and P2E3. Ground water flows from areas of higher head to areas of lower head.

The flow of freshwater at Transect A2 in Atlantic Beach is influenced at times by the movement of brackish water in the confining beds (Figure 3-15). During August 1984, freshwater was diverted from its downward migration routes to routes that followed the interface with the brackish water.

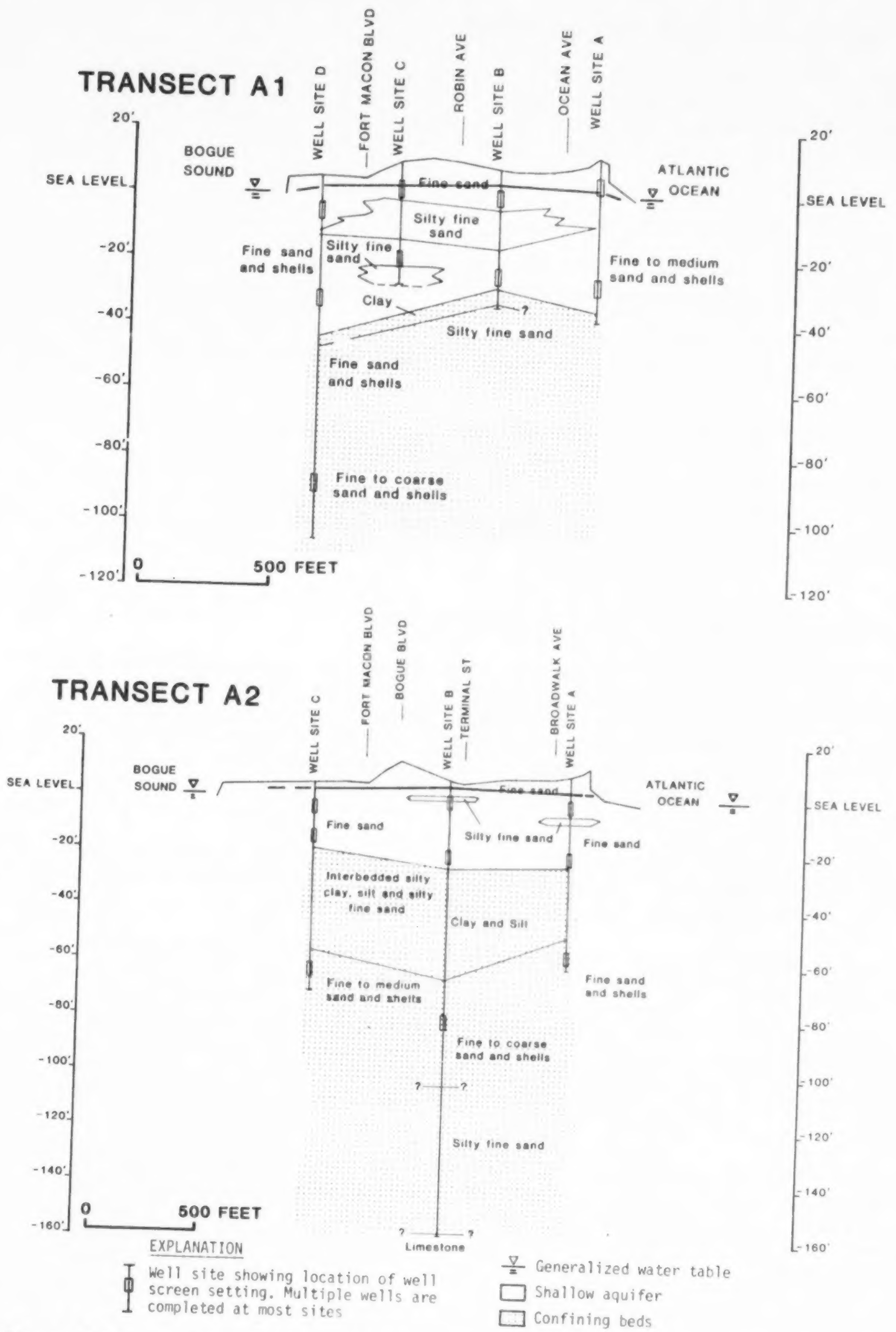

TRANSECT A1
20'
SEA LEVEL
-20'
-40'
-60'
-80'
-100'
-120'
WELL SITE D
FORT MACON BLVD
WELL SITE C
ROBIN AVE
WELL SITE B
OCEAN AVE
WELL SITE A
BOGUE SOUND
ATLANTIC OCEAN
Fine sand
Silty fine sand
Fine sand and shells
Silty fine sand
Clay
?
Fine to medium sand and shells
Silty fine sand
Fine sand and shells
Fine to coarse sand and shells
0
500 FEET
20'
SEA LEVEL
-20'
-40'
-60'
-80'
-100'
-120'
TRANSECT A2
20'
SEA LEVEL
-20'
-40'
-60'
-80'
-100'
-120'
-140'
-160'
WELL SITE C
FORT MACON BLVD
BOGUE BLVD
WELL SITE B
TERMINAL ST
BROADWALK AVE
WELL SITE A
BOGUE SOUND
ATLANTIC OCEAN
Fine sand
Fine sand
Silty fine sand
Fine sand
Interbedded silty clay, silt and silty fine sand
Clay and Silt
Fine to medium sand and shells
Fine sand and shells
Fine to coarse sand and shells
? ?
Silty fine sand
? ?
Limestone
0
500 FEET
20'
SEA LEVEL
-20'
-40'
-60'
-80'
-100'
-120'
-140'
-160'
EXPLANATION
Well site showing location of well screen setting. Multiple wells are completed at most sites
Generalized water table
Shallow aquifer
Confining beds

Figure 3-13. Hydrogeologic cross-sections for the shallow aquifer at Atlantic Beach.

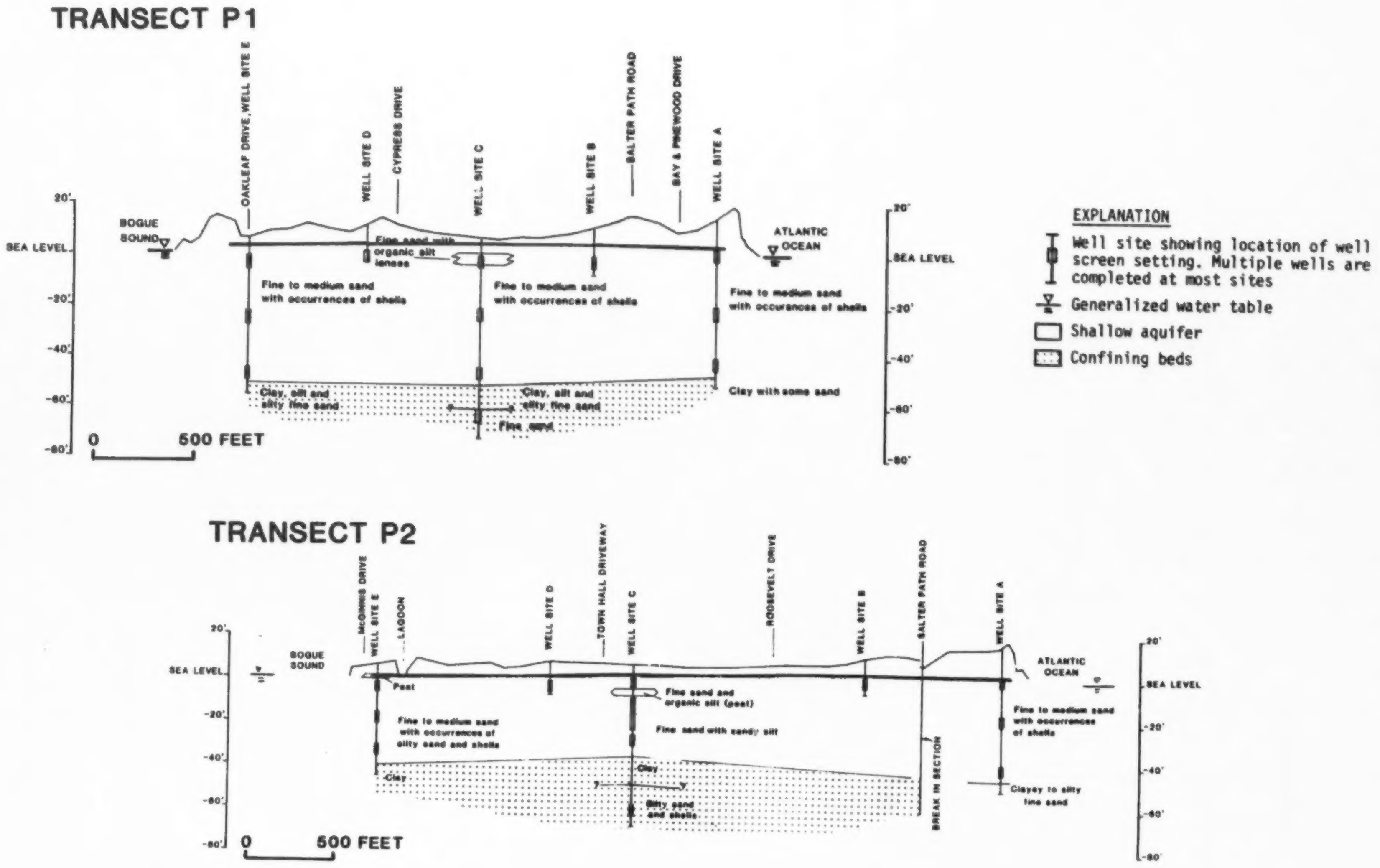

TRANSECT P1
OAKLEAF DRIVE, WELL SITE E
WELL SITE D
CYPRESS DRIVE
WELL SITE C
WELL SITE B
SALTER PATH ROAD
BAY & PINEWOOD DRIVE
WELL SITE A
20'
SEA LEVEL
-20'
-40'
-60'
-80'
BOGUE SOUND
ATLANTIC OCEAN
Fine sand with organic silt lenses
Fine to medium sand with occurrences of shells
Fine to medium sand with occurrences of shells
Fine to medium sand with occurances of shells
Clay, silt and silty fine sand
Clay, silt and silty fine sand
Fine sand
Clay with some sand
0
500 FEET
EXPLANATION
Well site showing location of well screen setting. Multiple wells are completed at most sites
Generalized water table
Shallow aquifer
Confining beds
TRANSECT P2
McGINNIS DRIVE
WELL SITE E
LAGOON
WELL SITE D
TOWN HALL DRIVEWAY
WELL SITE C
ROOSEVELT DRIVE
WELL SITE B
SALTER PATH ROAD
WELL SITE A
BOGUE SOUND
ATLANTIC OCEAN
Peat
Fine to medium sand with occurrences of silty sand and shells
Fine sand and organic silt (peat)
Fine sand with sandy silt
Clay
Clay
?
Silty sand and shells
BREAK IN SECTION
Fine to medium sand with occurrences of shells
Clayey to silty fine sand
0
500 FEET

Figure 3-14. Hydrogeologic cross-sections for the shallow aquifer at Pine Knoll Shores.

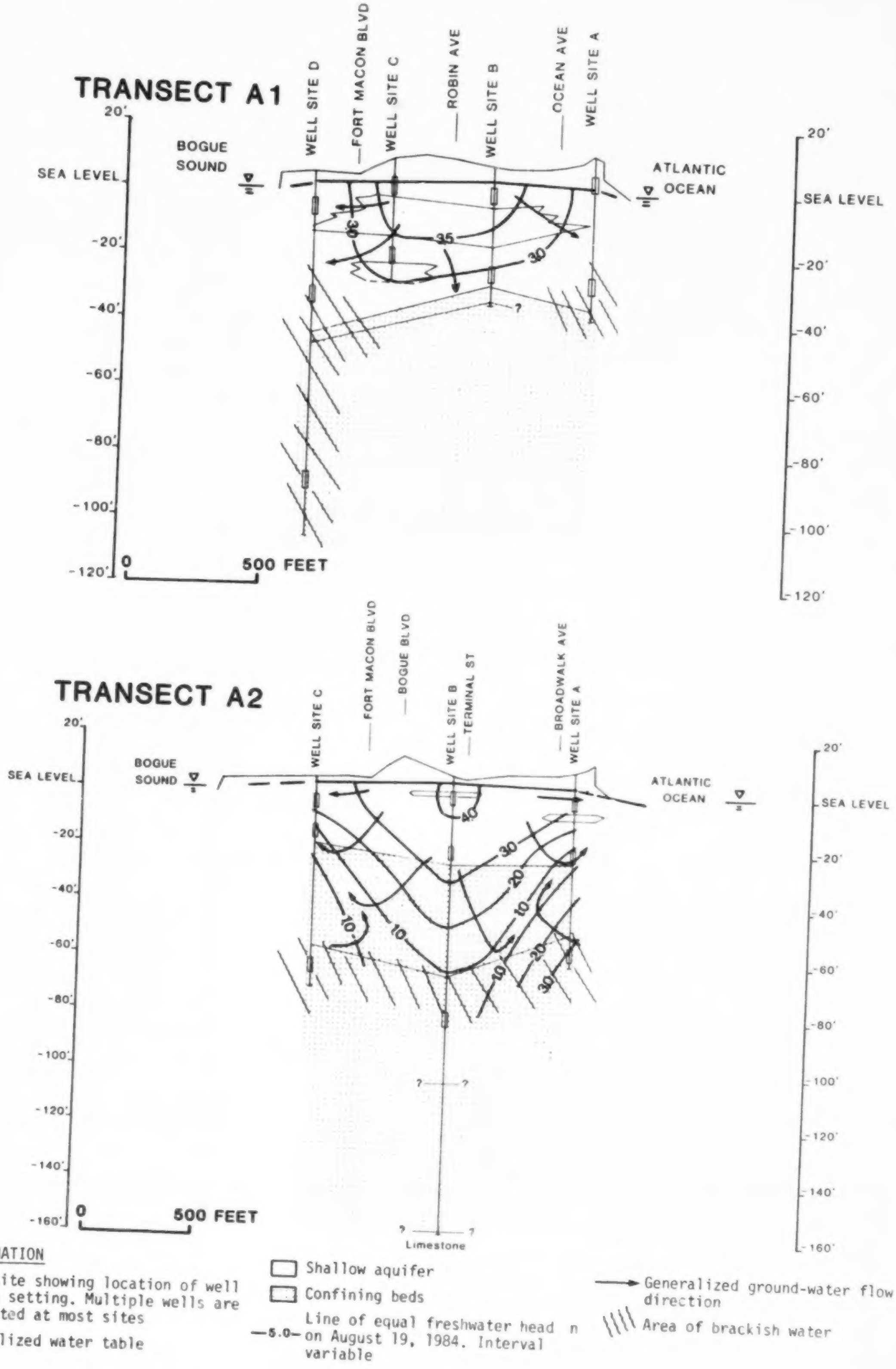
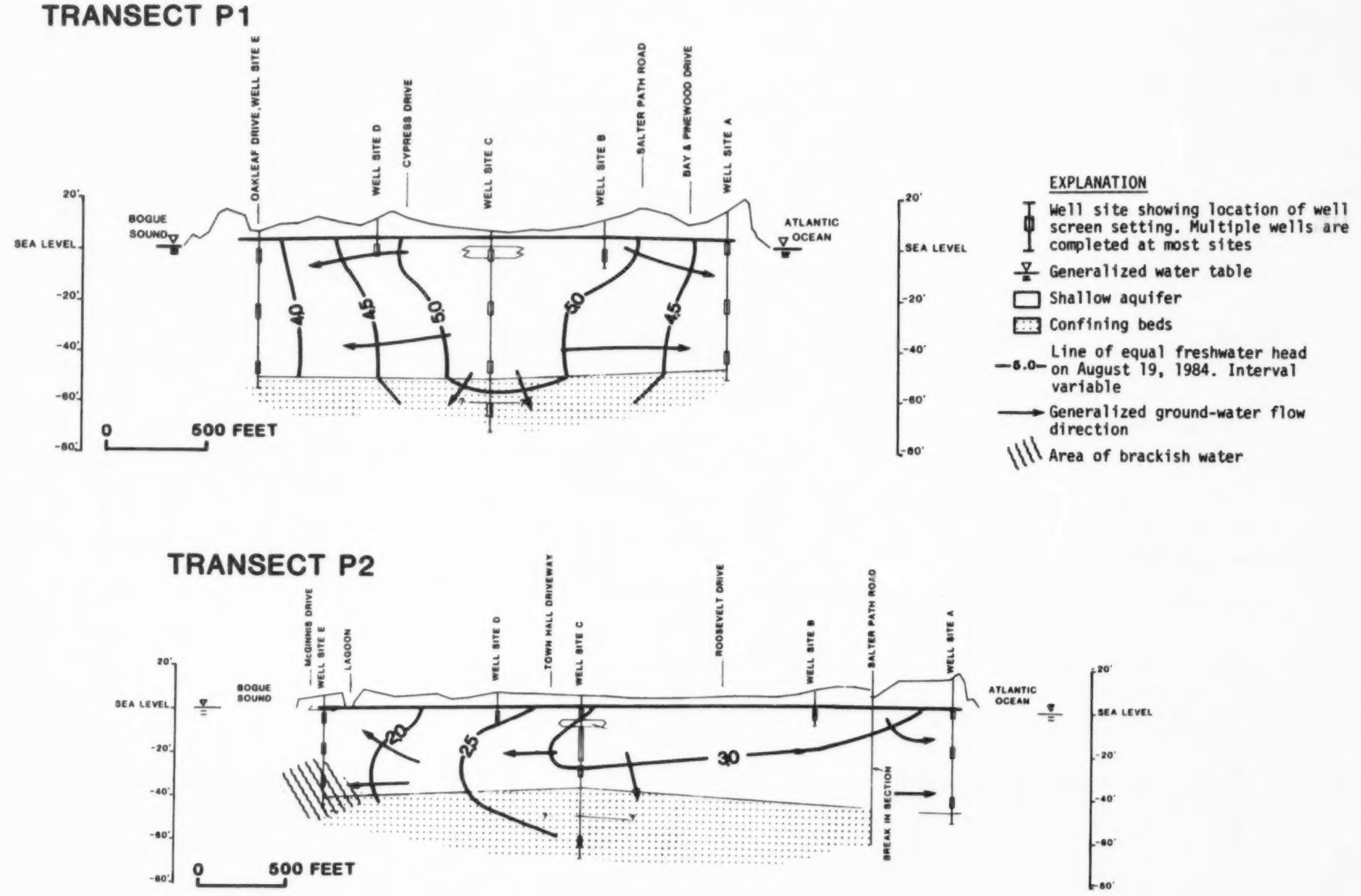

TRANSECT A1
WELL SITE D
FORT MACON BLVD
WELL SITE C
ROBIN AVE
WELL SITE B
OCEAN AVE
WELL SITE A
BOGUE SOUND
ATLANTIC OCEAN
SEA LEVEL
20'
-20'
-40'
-60'
-80'
-100'
-120'
30
35
30
0
500 FEET
TRANSECT A2
WELL SITE C
FORT MACON BLVD
BOGUE BLVD
WELL SITE B
TERMINAL ST
BROADWALK AVE
WELL SITE A
BOGUE SOUND
ATLANTIC OCEAN
SEA LEVEL
20'
-20'
-40'
-60'
-80'
-100'
-120'
-140'
-160'
40
30
20
10
10
10
10
20
30
Limestone
0
500 FEET
EXPLANATION
Well site showing location of well screen setting. Multiple wells are completed at most sites
Generalized water table
Shallow aquifer
Confining beds
—5.0— Line of equal freshwater head on August 19, 1984. Interval variable
Generalized ground-water flow direction
Area of brackish water

Figure 3-15. Ground-water flowpaths in the shallow aquifer at Atlantic Beach on August 19, 1984.


TRANSECT P1

TRANSECT P2

EXPLANATION
Well site showing location of well screen setting. Multiple wells are completed at most sites
Generalized water table
Shallow aquifer
Confining beds
—5.0— Line of equal freshwater head on August 19, 1984. Interval variable
Generalized ground-water flow direction
Area of brackish water
OAKLEAF DRIVE, WELL SITE E
WELL SITE D
CYPRESS DRIVE
WELL SITE C
WELL SITE B
SALTER PATH ROAD
BAY & PINEWOOD DRIVE
WELL SITE A
BOGUE SOUND
ATLANTIC OCEAN
SEA LEVEL
20'
-20'
-40'
-60'
-80'
40
45
50
0
500 FEET
McGINNIS DRIVE
WELL SITE E
LAGOON
TOWN HALL DRIVEWAY
ROOSEVELT DRIVE
BREAK IN SECTION
20
25
30

Figure 3-16. Ground-water flowpaths in the shallow aquifer at Pine Knoll Shores on August 19, 1984.

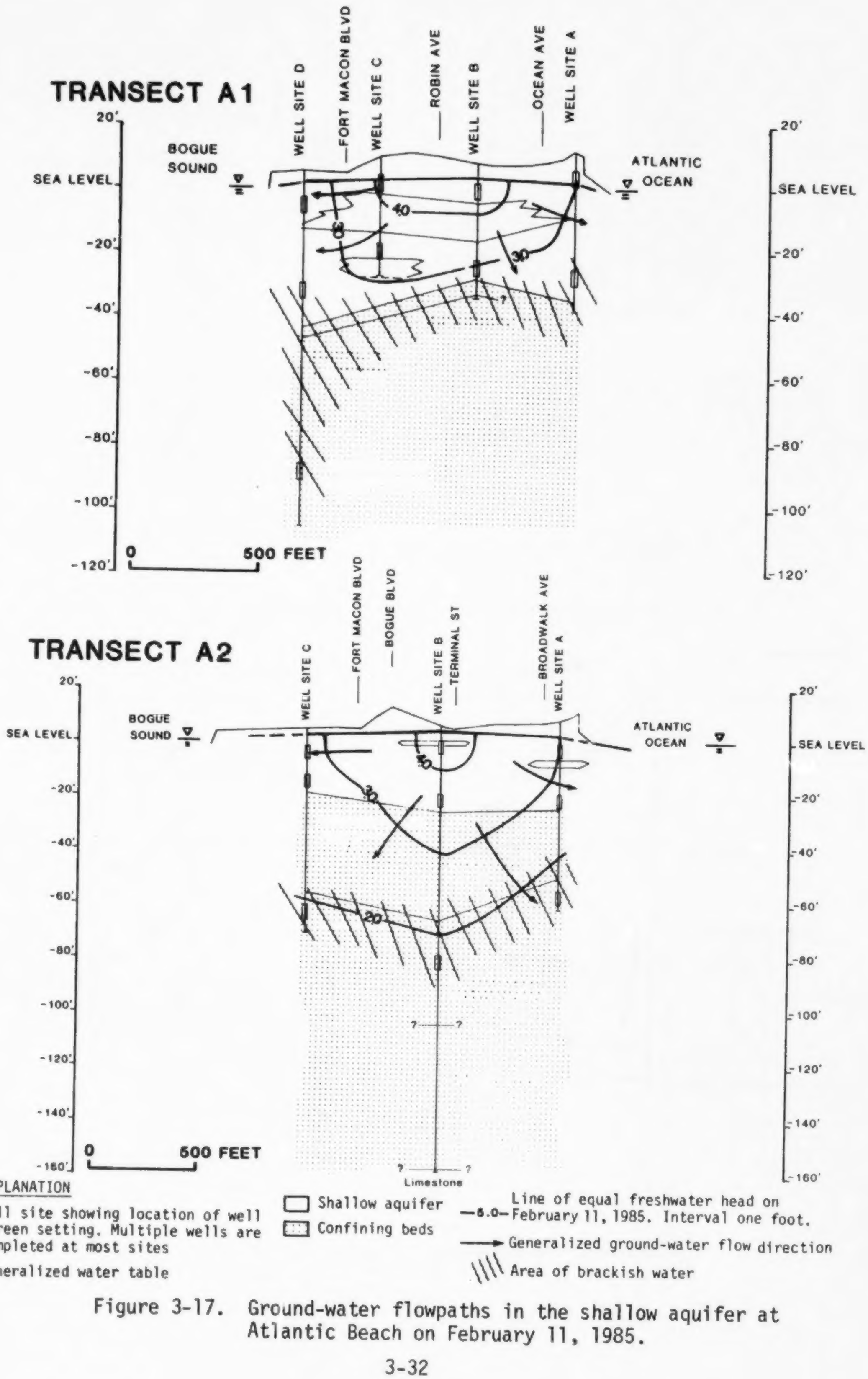

TRANSECT A1
WELL SITE D
FORT MACON BLVD
WELL SITE C
ROBIN AVE
WELL SITE B
OCEAN AVE
WELL SITE A
BOGUE SOUND
ATLANTIC OCEAN
SEA LEVEL
20'
-20'
-40'
-60'
-80'
-100'
-120'
40
30
30
?
0
500 FEET
TRANSECT A2
WELL SITE C
FORT MACON BLVD
BOGUE BLVD
WELL SITE B
TERMINAL ST
BROADWALK AVE
WELL SITE A
BOGUE SOUND
ATLANTIC OCEAN
SEA LEVEL
20'
-20'
-40'
-60'
-80'
-100'
-120'
-140'
-160'
40
30
20
?
?
Limestone
0
500 FEET
EXPLANATION
Well site showing location of well screen setting. Multiple wells are completed at most sites
Generalized water table
Shallow aquifer
Confining beds
5.0 Line of equal freshwater head on February 11, 1985. Interval one foot.
Generalized ground-water flow direction
Area of brackish water

Figure 3-17. Ground-water flowpaths in the shallow aquifer at Atlantic Beach on February 11, 1985.

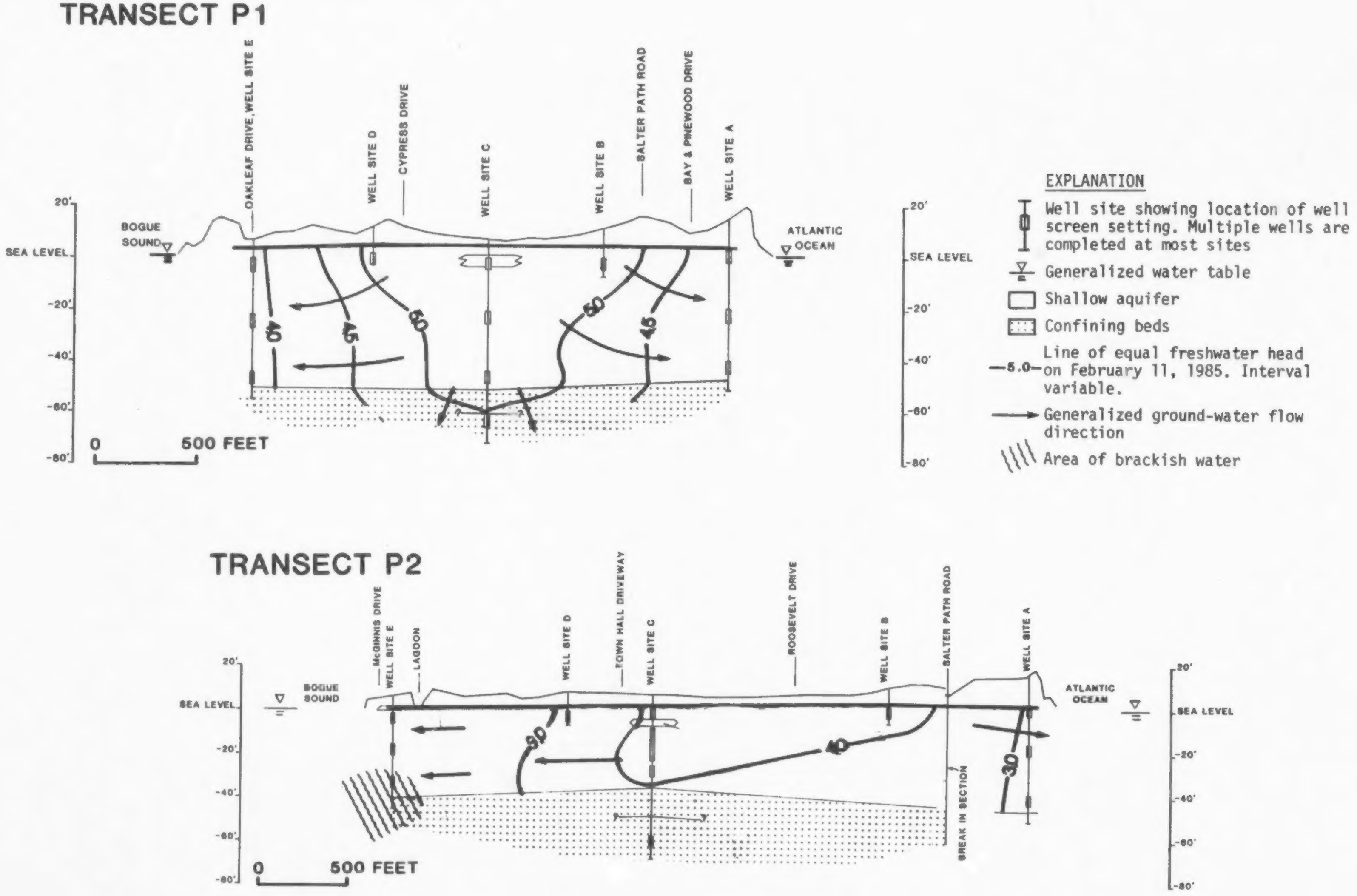

TRANSECT P1
OAKLEAF DRIVE, WELL SITE E
WELL SITE D
CYPRESS DRIVE
WELL SITE C
WELL SITE B
SALTER PATH ROAD
BAY & PINEWOOD DRIVE
WELL SITE A
BOGUE SOUND
ATLANTIC OCEAN
20'
SEA LEVEL
-20'
-40'
-60'
-80'
40
45
50
0 500 FEET
EXPLANATION
Well site showing location of well screen setting. Multiple wells are completed at most sites
Generalized water table
Shallow aquifer
Confining beds
—5.0— Line of equal freshwater head on February 11, 1985. Interval variable.
Generalized ground-water flow direction
Area of brackish water
TRANSECT P2
McGINNIS DRIVE
WELL SITE E
LAGOON
WELL SITE D
TOWN HALL DRIVEWAY
WELL SITE C
ROOSEVELT DRIVE
WELL SITE B
SALTER PATH ROAD
WELL SITE A
BOGUE SOUND
ATLANTIC OCEAN
BREAK IN SECTION
20'
SEA LEVEL
-20'
-40'
-60'
-80'
30
40
50
0 500 FEET

Figure 3-18. Ground-water flowpaths in the shallow aquifer at Pine Knoll Shores on February 11, 1985.

Movement of brackish water parallel to freshwater was not detected at the other transects in the study area in August 1984. However, brackish water was found in the confining beds at Transect A1 and at the base of the shallow aquifer near Bogue Sound at Transect P2 (Figures 3-15 and 3-16).

Normal ground-water flow patterns along Transects A1, P1 and P2 varied only slightly between summer and winter. Flow patterns in August 1984, which are representative of summer conditions, are shown in Figures 3-15 and 3-16. Flow patterns in February 1985, which are representative of winter conditions, are shown in Figures 3-17 and 3-18.

The heavy rains and high tides resulting from hurricane Diane in September 1984 appeared to have significantly altered ground-water flow paths along Transect A2. Movement of brackish water parallel to freshwater was not detected along this transect between September 1984 and May 1985. The typical flow pattern along Transect A2 from the late fall of 1984 to May 1985 is shown in Figure 3-17.

The September rains and high tides caused some changes in ground-water flow along Transects A1, P1 and P2. These changes generally included a reduction in ground-water flow toward the ocean. By December, however, ground-water flow was essentially the same as that normally observed during the study.

The ground-water flow velocity through the shallow aquifer varies from less than 0.1 ft/day along Transect P2 to about 1.6 ft/day along Transect A1 (Table 3-4). These velocities were computed using equation (1). The hydraulic conductivity of the aquifer used in the computations is 63 ft/day. This value was determined from an aquifer pumping test performed at well P2C2. The effective porosity of the aquifer was computed as 0.20 by correlating precipitation measured at Atlantic Beach with changes in water levels observed in well P2C1 (Appendix F). Well P2C1 was equipped with a continuous stage recorder for monitoring water levels.

The shallow aquifer system ground-water flow velocities found elsewhere on the barrier islands fall between those found in the Atlantic Beach/Pine Knoll Shores area. The average flow velocity in the shallow aquifer on Bodie Island in the Kill Devils Hills study area is about 0.7 feet per day (see Section 3.1.2.2). The average flow velocity in the shallow aquifer at the Cape Hatteras National Seashore, located northeast of Bogue Banks and south of Bodie Island, is about one foot per day (Winner, 1975).

The flowpath traveled by a water particle and the flow velocity of the particle determines the time that the particle will remain in the aquifer. The travel time from the ground-water divide on the island to the ocean along flowpaths at Transect A1 is a little more than one year. Water traveling from the ground-water divide at Transect P2 may remain in the aquifer for several decades before discharging to the sound. Flow times along transects from the ground-water divide to the ocean and sound are presented in Table 3-4.

TABLE 3-4

GROUND-WATER FLOW VELOCITIES AND TRAVEL TIMES ALONG TRANSECTS IN ATLANTIC BEACH AND PINE KNOLL SHORES

Site	Distance between sites (feet)	Mean water-table elevation (MSL)	Hydraulic gradient between sites (feet/foot)	Flow velocity (feet/day)	Travel time between sites (days)	Cumulative travel time to sound or ocean (days)	Remarks
Transect A1							
B		4.2				0	Sound side of transect
	375		8.00×10^{-4}	0.25	1490		
C		3.9				1490	
	300		5.00×10^{-3}	1.58	190		
D		2.4				1680	
B		4.2				0	Ocean side of transect
	375		2.67×10^{-3}	0.84	440		
A		3.2				440	
Transect A2							
B		4.2				0	Sound side of transect
	630		2.54×10^{-3}	0.80	790		
C		2.6				790	
B		4.2				0	Ocean side of transect
	565		1.77×10^{-3}	0.56	1010		
A		3.2				1010	
Transect P1							
C		5.4				0	Sound side of transect
	552		1.09×10^{-3}	0.34	1610		
D		4.8				1610	
	600		2.00×10^{-3}	0.63	950		
E		3.6				2560	
C		5.4				0	Ocean side of transect
	588		5.10×10^{-4}	0.16	3660		
B		5.1				3660	
	600		1.33×10^{-3}	0.42	1430		
A		4.3				5090	
Transect P2							
B		4.0				0	Sound side of transect
	1610		3.11×10^{-4}	0.10	16500		
C		3.5				16500	
	515		1.75×10^{-3}	0.55	940		
D		2.6				16990	
	960		1.04×10^{-4}	0.03	29300		
E		2.5				46290	
B		4.0				0	Ocean side of transect
	585		1.37×10^{-3}	0.43	1360		
A		3.2				1360	

The shortest residence times in the shallow aquifer occur at the water table surface near the ocean and sound. Flowpaths are shortest and flow velocities are greatest in these areas. The travel time to the ocean along Transects A1 and P1 for water particles entering the shallow aquifer at well sites A1A or P1A is typically one to two months. The travel time from well site A1D to the sound along the water table at Transect A1 is about two months, and the travel time from well site P1E to the sound along the water table at Transect P1 is about seven months. These travel times are representative residence times for water that enters the shallow aquifer in developed areas near the ocean and sound.

3.2.2.3 Water Levels

Ground-water levels in the shallow aquifer varied in response to recharge and discharge. Water levels would rise rapidly in response to recharge from precipitation and fall gradually at other times due to discharge. The long-term water-level recession rate due to discharge is about 0.03 ft/day at well P2C1. Discharge includes seepage of water to the ocean and sound, transpiration by vegetation and evaporation. Water-level variations in Well P2C1, located in Pine Knoll Shores and generally representative of recharge and discharge conditions in the Atlantic Beach/Pine Knoll Shores study area, are presented in Figure 3-19.

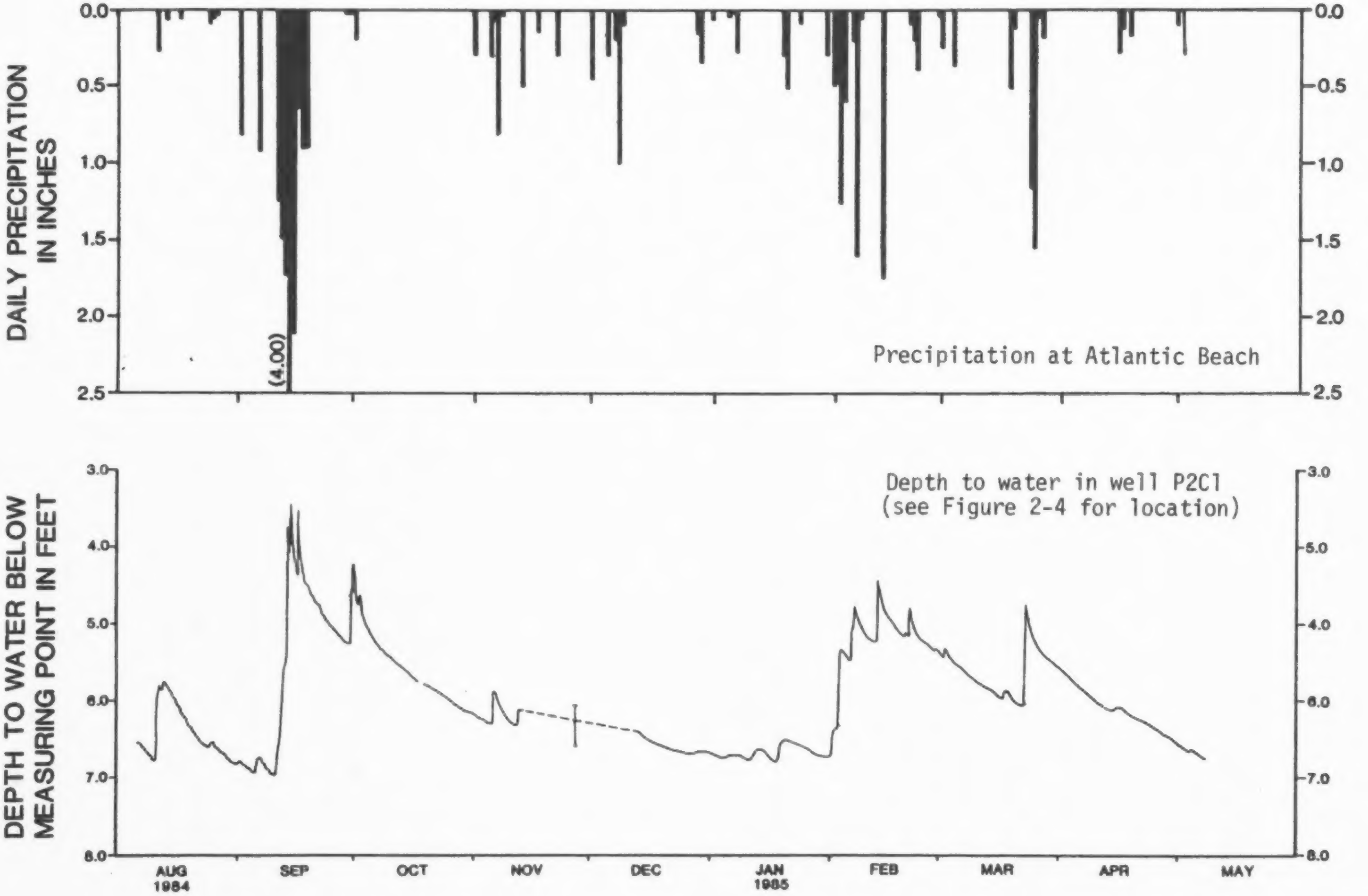
Evapotranspiration noticeably affected water levels in Pine Knoll Shores at well P2C1 during the growing season. Water-level declines would steepen during daylight hours in response to the demands of evapotranspiration. These effects were evident in August 1984, when data collection began, and lasted until late October 1984. They became evident again in April 1985.

Water levels in some of the other shallow wells within Pine Knoll Shores appear to behave similarly to well P2C1. Diurnal fluctuations in water levels that could be attributed to evapotranspiration were observed in these wells during 24-hour measurements in August 1984, whereas there were no apparent diurnal fluctuations in water levels during 24-hour measurements in February 1985.

Water-level declines in Pine Knoll Shores during August were 0.01 to 0.02 ft/day greater than those that occurred during the non-growing season. This added decline is largely the result of transpiration by vegetation and amounts to 0.7 to 1.5 inches per month.

Diurnal water-level fluctuations that could be attributed to evapotranspiration were not apparent in August 1984 or February 1985 from 24-hour measurements made in wells located in Atlantic Beach. The scarcity of vegetation in Atlantic Beach probably accounts for the lack in diurnal water-level fluctuations during the growing season.

The influence of tidal fluctuations on water levels appears to be confined to areas adjacent to the ocean and sound. Water-level variations of 0.1 to 0.2 feet, probably caused by tidal influences, were observed in wells adjacent to the ocean and sound during 24-hour periods in August 1984 and again in February 1985. Water levels in the other wells at these times did not appear to be influenced by tidal fluctuations.



EXPLANATION

(4.00) Total rainfall for the day when the total exceeds the scale

------ Dashed line represents missing water level record

Figure 3-19. Relation between ground-water levels and precipitation in the Atlantic Beach/Pine Knoll Shores study area.

3.2.2.4 Net Ground-Water Recharge

Net recharge to the shallow aquifer is the difference between water gains and water losses at the water-table surface. Water gains occur as infiltration from precipitation and wastewater disposal. Water losses occur as a result of evapotranspiration. Changes in water stored in the unsaturated zone overlying the shallow aquifer influences the net recharge and must also be taken into account.

Net recharge along each of the transects was computed using a monthly water budget for water gains and losses at the water-table surface (see Section 3.1.2.4). Summaries of these computations for transects in Atlantic Beach and Pine Knoll Shores are presented in Tables 3-5 and 3-6, respectively.

In Atlantic Beach, precipitation and wastewater are both important sources for recharge to the shallow aquifer. Precipitation accounted for approximately 70 percent of the recharge along Transects A1 and A2 and wastewater accounted for the remaining 30 percent.

In Pine Knoll Shores, precipitation is the major source and wastewater is a minor source for recharge to the shallow aquifer. Precipitation accounted for approximately 98 percent of the recharge along Transect P1 and about 88 percent of the recharge along Transect P2. Wastewater accounted for the remainder of the recharge received along these transects.

All precipitation was assumed to infiltrate into the soil in these analyses. This assumption is reasonable as the soil is permeable and little or no runoff is observed during most rains. Also, there is no stormwater collection system in Atlantic Beach or Pine Knoll Shores to collect and convey runoff from buildings and streets. Runoff generally ponds in low areas and eventually seeps into the ground or evaporates.

Monthly precipitation for the analyses was determined from daily rainfall records collected by the Atlantic Beach public works department. Data for June, July and part of August were supplemented with that collected by the National Weather Service at Moorehead City, located about one mile north of Atlantic Beach.

Wastewater disposal for the analyses was assumed to be equal to water use from public supplies. Most water used in Atlantic Beach and Pine Knoll Shores is treated on-site and disposed of by infiltration of the water into the ground. Also, water from private shallow wells does not materially affect the water balance for the shallow aquifer.

Monthly wastewater disposal along the transects in Pine Knoll Shores was estimated from the quarterly water use records for residents along the transects. The ratio of monthly to quarterly water use, needed to distribute water use on a monthly basis, was assumed to be the same as that observed at Atlantic Beach.

TABLE 3-5

SUMMARY OF RECHARGE COMPUTATIONS FOR TRANSECTS IN ATLANTIC BEACH[(1)]

Transect ID	Parameter (inches)	1984							1985					Totals
		June	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	
A1	I_p	6.94	8.54	1.42	13.98	0.51	2.58	2.15	2.54	6.43	3.93	0.71	7.38	57.11
	I_w	1.63	1.84	1.90	0.99	0.58	0.52	0.70	0.47	0.23	0.39	0.71	1.81	11.77
	ΔS	0	0	-0.80	0.80	-0.80	0.80	0	0	0	0	-0.80	0.80	0.00
	ET	5.71	6.25	2.22	3.92	1.31	1.27	1.21	0.20	0.52	1.37	1.51	5.33	30.82
	W	2.86	4.13	1.90	10.25	0.58	1.03	1.64	2.81	6.14	2.95	0.71	3.06	38.06
A2	I_p	6.94	8.54	1.42	13.98	0.51	2.58	2.15	2.54	6.43	3.93	0.71	7.38	57.11
	I_w	1.13	1.47	1.55	0.99	0.56	0.53	0.47	0.63	0.89	0.78	0.56	0.91	10.47
	ΔS	0	0	-0.80	0.80	-0.80	0.80	0	0	0	0	-0.80	0.80	0.00
	ET	5.71	6.25	2.22	3.92	1.31	1.27	1.21	0.20	0.52	1.37	1.51	5.33	30.82
	W	2.36	3.76	1.55	10.25	0.56	1.04	1.41	2.97	6.80	3.34	0.56	2.16	36.76

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(1) All values are reported in inches.

TABLE 3-6

SUMMARY OF RECHARGE COMPUTATIONS FOR TRANSECTS IN PINE KNOLL SHORES[1]

Transect ID	Parameter (inches)	1984							1985					Totals
		June	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	
P1	I_p	6.94	8.54	1.42	13.98	0.51	2.58	2.15	2.54	6.43	3.93	0.71	7.38	57.11
	I_w	0.06	0.07	0.07	0.05	0.05	0.05	0.05	0.03	0.03	0.03	0.03	0.05	0.57
	ΔS	0	0	-0.80	0.80	-0.80	0.80	0	0	0	0	-0.80	0.80	0.00
	ET	5.71	6.25	2.22	3.92	1.31	1.27	1.21	0.20	0.52	1.37	1.51	5.33	30.82
	W	1.29	2.36	0.07	9.31	0.05	0.56	0.99	2.37	5.94	2.59	0.03	1.30	26.86
P2	I_p	6.94	8.54	1.42	13.98	0.51	2.58	2.15	2.54	6.43	3.93	0.71	7.38	57.11
	I_w	0.25	0.54	0.54	0.36	0.14	0.14	0.14	0.14	0.14	0.14	0.36	0.58	3.47
	ΔS	0	0	-0.80	0.80	-0.80	0.80	0	0	0	0	-0.80	0.80	0.00
	ET	5.71	6.25	2.22	3.92	1.31	1.27	1.21	0.20	0.52	1.37	1.51	5.33	30.82
	W	1.48	2.83	0.54	9.62	0.14	0.65	1.08	2.48	6.05	2.70	0.36	1.83	29.76

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[1] All values are reported in inches .

Monthly soil moisture changes and monthly evapotranspiration used in the analyses were computed using methods outlined by the EPA (Fenn et al., 1975). These methods are described in Appendix G.

3.2.2.5 Water Quality

Ground-water samples were taken periodically for the analysis of selected parameters (Table 3-7). Water samples were collected in July 1984, October 1984, January 1985 and April 1985 along the designated high population density transects A1 and A2, in July 1984 and January 1985 along Transect P1, the designated medium population density transect, and in January 1985 along the designated low population density transect, Transect K3.

Water samples were collected with two objectives in mind. One objective was to define the relationship between saltwater and freshwater in the shallow aquifer. The second objective was to define the current impact of wastewater disposal on the quality of water in the shallow aquifer.

Additionally, water samples were collected along Transects A1 and A2 in September 1984 to aid in assessing the effects of hurricane Diane on the ground-water system.

3.2.2.5.1 Relationship Between Freshwater and Saltwater

Measured chemical properties of the ground water used to aid in defining saltwater intrusion into the shallow aquifer included sodium concentration, chloride concentration, total dissolved solids concentration and specific conductance. Sodium and chloride are the major constituents in saltwater. Total dissolved solids measures all solids in solution in the water, including sodium and chloride. Specific conductance measures the ability of water to conduct an electrical current, and generally increases with an increase in total dissolved solids content in the water.

Elevated total dissolved solids concentrations had a strong correlation with elevated sodium and chloride concentrations in water from the shallow aquifer along both transects in Atlantic Beach, and is a good indicator of saltwater intrusion into the aquifer. The total dissolved solids content in the water was used to determine the presence of saltwater and freshwater in the shallow aquifer.

Elevated specific conductances also correlated well with increased sodium and chloride concentrations in water from the aquifer.

Variations in the total dissolved solids content of water in the shallow aquifer at Atlantic Beach are apparent (Figures 3-20 and 3-21). Freshwater generally exists at the surface of the shallow aquifer. However, the total dissolved solids content of the water increases with depth, indicating an increased influence from saltwater intrusion into the aquifer. At three of the four well sites along Transect A1, the total dissolved solids content of the water increases to brackish levels below the depth of the shallowest monitoring wells (Table 3-7). Only

TABLE 3-7

SUMMARY OF GROUND-WATER QUALITY ANALYSES FOR ATLANTIC BEACH/PINE KNOLL SHORES[1]

Well ID	Sampling date	Sodium	Chloride	Total dissolved solids	Ammonia (mg/l as N)	Nitrate plus nitrite (mg/l as N)	Alkalinity (mg/l as $CaCO_3$)	Hardness (mg/l as $CaCO_3$)	MBAS (mg/l)	Orthophosphate (mg/l as P)	Temperature °C	Specific conductance (µmhos/cm)	pH (s.u.)	Fecal coliform (colonies per 100/ml)
Atlantic Beach Transect A1														
A1A1	15Jul84	36	75	390	0.02	<0.05	148	158	0.10	<0.01	23	486	7.60	36
	17Sep84	35	67	318	<0.01	0.25	197	586	<0.02	0.37	25	470	6.73	<1
	18Oct84	33	47	320	0.50	<0.05	166	270	<0.02	0.51	20	495	7.10	<1
	19Jan85	45	50	284	0.11	<0.05	166	210	<0.02	0.45	17	400	7.38	<1
	11Apr85	34	59	286	2.11	<0.05	137	435	0.04	1.41	17	400	7.62	<1
A1A3	15Jul84	354	540	1248	0.56	<0.05	248	576	0.10	1.41	22	1940	7.79	28
	17Sep84	397	640	1348	0.71	0.36	268	720	<0.02	0.36	23	2150	7.09	<1
	18Oct84	335	493	1208	1.02	<0.05	246	430	<0.02	0.67	17	1950	7.55	1
	19Jan85	822	761	1450	0.62	<0.05	264	315	<0.02	0.16	21	5000	7.74	<1
	11Apr85	274	637	1404	1.77	<0.05	253	333	<0.02	0.16	19	1580	7.78	<1
A1B1	15Jul84	4	6	240	0.28	0.47	104	150	0.11	<0.01	25	232	7.91	<1
	17Sep84	5	12	555	<0.01	0.29	102	420	<0.02	0.03	25	215	7.04	<1
	18Oct84	6	11	252	<0.01	<0.05	198	225	<0.02	0.20	20	375	7.20	<1
	19Jan85	51	16	162	0.16	<0.05	142	155	<0.02	0.10	16	240	7.72	2
	11Apr85	21	37	273	0.52	<0.05	157	232	<0.02	0.07	18	410	7.61	<1
A1B3	15Jul84	12	17	308	<0.01	0.12	135	550	0.09	1.41	23	335	7.77	<1
	17Sep84	66	127	527	0.13	0.67	153	880	<0.02	0.22	23	700	6.96	<1
	18Oct84	241	441	278	0.74	<0.05	177	620	<0.02	0.42	18	1750	7.23	<1
	19Jan85	1068	925	1968	1.06	<0.05	216	595	<0.02	0.31	22	5000	7.64	<1
	11Apr85	436	970	2124	1.81	<0.05	226	611	<0.02	0.72	20	3300	7.66	<1
A1C1	15Jul84	21	17	336	0.10	0.07	139	210	<0.02	0.13	24	366	7.26	56
	17Sep84	16	13	214	<0.01	0.16	140	820	<0.02	0.16	25	310	6.60	<1
	18Oct84	16	20	244	0.51	<0.05	173	470	<0.02	0.54	21	350	7.15	<1
	19Jan85	65	22	206	0.45	<0.05	200	260	<0.02	0.38	17	350	7.52	<1
	11Apr85	14	24	229	0.42	<0.05	151	278	<0.02	0.22	19	362	7.48	<1
A1C3	15Jul84	22	44	404	0.05	<0.05	252	524	<0.02	1.02	22	620	7.44	>250
	17Sep84	36	43	335	0.21	0.55	220	2100	<0.02	<0.01	23	490	6.66	<1
	18Oct84	18	26	346	0.86	<0.05	194	625	0.04	1.70	20	530	7.25	<1
	19Jan85	96	76	398	0.18	<0.05	214	245	<0.02	0.10	22	700	7.71	<1
	11Apr85	56	96	456	1.64	<0.05	222	546	<0.02	0.62	20	750	7.52	<1

TABLE 3-7
(continued)
SUMMARY OF GROUND-WATER QUALITY ANALYSES FOR ATLANTIC BEACH/PINE KNOLL SHORES

Well ID	Sampling date	Sodium	Chloride	Total dissolved solids	Ammonia (mg/l as N)	Nitrate plus nitrite (mg/l as N)	Alkalinity (mg/l as $CaCO_3$)	Hardness (mg/l as $CaCO_3$)	MBAS (mg/l)	Orthophosphate (mg/l as P)	Temperature °C	Specific conductance (μmhos/cm)	pH (s.u.)	Fecal coliform (colonies per 100/ml)
Atlantic Beach Transect A1														
A1D1	15Jul84	72	46	662	1.53	<0.05	369	330	0.11	1.11	25	850	7.14	13
	17Sep84*	82	48	509	2.01	0.09	353	366	<0.02	0.39	25	750	6.39	>740
	18Oct84	84	37	580	4.54	<0.05	385	340	0.19	2.60	21	880	6.74	>730
	19Jan85	135	41	562	8.68	<0.05	432	355	0.05	2.29	19	950	6.88	<1
	11Apr85	76	40	501	5.49	<0.05	373	287	0.26	2.70	19	880	6.92	<1
A1D2	15Jul84	467	830	1667	0.61	<0.05	217	350	0.03	0.17	24	2910	7.25	22
	17Sep84*	380	700	1318	0.46	0.62	221	980	<0.02	0.16	23	2010	7.33	>170
	18Oct84	414	687	1498	1.14	0.44	218	410	0.09	0.39	17	2530	7.13	4
	19Jan85	455	715	1520	0.39	0.06	223	310	<0.02	0.26	21	2300	7.80	<1
	11Apr85	282	1070	1400	1.25	<0.05	225	361	0.12	0.33	20	2410	7.75	<1
A1D3	15Jul84	576	1250	2830	0.95	<0.05	252	2300	0.18	3.56	23	4320	7.86	<1
	17Sep84*	102	138	418	0.24	0.88	220	228	<0.02	0.45	22	490	6.73	>450
	18Oct84	297	536	512	1.56	<0.05	208	1495	0.04	0.66	17	5900	6.82	4
	19Jan85	802	1999	4060	2.85	<0.05	252	1055	<0.02	0.13	24	12500	7.56	<1
	11Apr85	1110	2550	5082	9.10	0.23	266	2759	<0.02	6.30	20	6600	7.47	<1
Transect A2														
A2A1	15Jul84	21	33	310	<0.01	0.17	174	340	<0.02	0.06	24	448	7.81	2
	17Sep84	22	31	317	0.07	0.98	203	300	<0.02	<0.01	23	410	7.03	2
	18Oct84	24	26	274	0.14	0.29	187	250	0.05	0.01	20	365	6.60	<1
	19Jan85	65	32	234	0.14	0.12	182	216	<0.02	0.11	19	355	7.71	<1
	11Apr85	26	37	286	0.51	<0.05	191	211	<0.02	0.13	18	459	7.67	<1
A2A3	15Jul84	46	60	474	0.21	<0.05	317	374	<0.02	0.41	21	810	7.84	<1
	17Sep84	50	33	647	1.43	1.01	271	224	0.05	<0.01	23	680	6.97	<1
	18Oct84	48	56	422	2.05	0.14	281	308	0.08	0.07	18	680	6.74	<1
	19Jan85	97	55	370	1.23	0.13	272	263	<0.02	0.11	20	680	7.54	<1
	11Apr85	43	52	408	6.10	<0.05	280	343	0.26	0.52	20	710	7.59	<1
A2A4	15Jul84	2510	4800	10934	1.43	<0.05	391	1700	<0.02	0.03	23	7500	7.67	<1
	17Sep84	2940	4474	9612	5.98	1.05	366	296	<0.02	0.42	22	13000	6.83	<1
	18Oct84	2581	4428	9596	6.11	<0.05	347	1400	0.06	0.43	17	13500	6.60	<1
	19Jan85	1274	4624	9246	12.50	<0.05	387	1410	<0.02	0.30	-	13000	7.40	<1
	11Apr85	1280	5000	9584	17.20	<0.05	378	1519	0.07	0.37	18	12100	7.49	<1

TABLE 3-7
(continued)
SUMMARY OF GROUND-WATER QUALITY ANALYSES FOR ATLANTIC BEACH/PINE KNOLL SHORES

Well ID	Sampling date	Sodium	Chloride	Total dissolved solids	Ammonia (mg/l as N)	Nitrate plus nitrite (mg/l as N)	Alkalinity (mg/l as $CaCO_3$)	Hardness (mg/l as $CaCO_3$)	MBAS (mg/l)	Orthophosphate (mg/l as P)	Temperature °C	Specific conductance (µmhos/cm)	pH (s.u.)	Fecal coliform (colonies per 100/ml)
Atlantic Beach (cont'd) Transect A2														
A2B1	15Jul84	21	32	362	0.38	<0.05	217	216	<0.02	0.10	27	550	7.51	<1
	17Sep84*	22	54	330	0.38	0.57	178	300	<0.02	<0.01	24	420	7.16	>6000
	18Oct84	19	26	556	0.66	<0.05	212	265	0.04	0.21	20	470	6.42	5
	19Jan85	83	34	342	0.78	<0.05	247	259	<0.02	0.30	17	430	7.25	3
	11Apr85	27	27	338	1.20	<0.05	273	278	0.07	0.31	20	580	7.23	<1
A2B3	15Jul84	30	59	346	0.38	<0.05	256	252	0.10	0.01	25	700	7.68	<1
	17Sep84*	29	77	386	0.77	0.05	228	520	<0.02	<0.01	22	490	7.34	>1400
	18Oct84	30	45	308	1.15	<0.05	267	370	0.06	0.38	20	650	6.61	>40
	19Jan85	77	41	320	0.31	0.35	273	261	<0.02	0.12	20	650	7.38	<1
	11Apr85	40	40	360	1.77	<0.05	266	361	0.07	0.44	21	640	7.55	<1
A2B4	15Jul84	490	1040	1984	1.23	<0.05	326	2640	0.11	<0.01	23	2840	7.67	<1
	17Sep84*	70	81	461	0.31	0.37	213	328	0.12	0.42	23	620	7.10	>1150
	18Oct84	289	452	1248	2.84	<0.05	277	390	0.06	0.21	17	2100	6.71	2
	19Jan85	592	878	1758	0.45	<0.05	314	409	0.02	0.02	22	2920	7.41	<1
	11Apr85	29	921	1947	8.30	1.24	298	500	0.06	0.12	20	3320	7.49	<1
A2C1	15Jul84*	28	36	582	0.73	<0.05	356	418	0.06	0.29	24	898	7.42	>150
	17Sep84*	36	76	651	0.05	0.25	324	208	0.15	0.07	24	780	6.94	>24900
	18Oct84	44	45	662	1.25	<0.05	399	510	0.05	0.12	20	1050	6.44	>2000
	19Jan85	80	38	650	0.18	<0.05	491	543	<0.02	0.16	16	910	7.06	>2
	11Apr85	142	33	635	4.30	<0.05	453	511	0.07	0.36	17	920	7.30	<1
A2C3	15Jul84*	90	77	604	0.33	<0.05	435	418	0.07	0.41	23	1000	7.71	>35800
	17Sep84*	64	52	546	0.54	0.54	358	308	0.04	0.04	23	750	7.41	>36800
	18Oct84	96	52	974	1.08	<0.05	458	365	0.05	0.15	18	890	6.80	>3000
	19Jan85	337	76	698	0.98	<0.05	547	291	0.02	0.12	20	1100	7.64	>6
	11Apr85	89	62	684	1.25	0.49	480	287	0.13	0.16	18	1100	7.72	<1
A2C4	15Jul84*	1720	3020	5172	1.05	<0.05	447	650	0.14	0.01	22	6500	7.74	>60
	17Sep84*	200	330	725	0.86	0.32	200	204	0.03	<0.01	22	1120	7.75	>4120
	18Oct84	659	919	1762	3.10	<0.05	260	410	0.06	0.13	18	4060	6.56	>600
	19Jan85	753	1906	3822	1.05	0.53	362	620	0.07	0.12	22	7000	7.67	<1
	11Apr85	95	1820	3298	1.16	0.06	293	463	0.14	0.21	19	7900	7.64	<1

TABLE 3-7
(continued)
SUMMARY OF GROUND-WATER QUALITY ANALYSES FOR ATLANTIC BEACH/PINE KNOLL SHORES

Well ID	Sampling date	Sodium	Chloride	Total dissolved solids	Ammonia (mg/l as N)	Nitrate plus nitrite (mg/l as N)	Alkalinity (mg/l as $CaCO_3$)	Hardness (mg/l as $CaCO_3$)	MBAS (mg/l)	Orthophosphate (mg/l as P)	Temperature °C	Specific conductance (µmhos/cm)	pH (s.u.)	Fecal coliform (colonies per 100/ml)
Pine Knoll Shores Transect P1														
P1A1	16Jul84	15	29	232	0.21	<0.05	109	174	0.09	0.06	23	355	7.60	<1
	19Jan85	74	48	306	0.16	<0.05	132	214	<0.02	0.18	19	400	7.74	<1
P1A2	16Jul84	48	41	276	0.29	<0.05	148	350	<0.02	0.74	22	400	7.84	<1
	19Jan85	111	60	264	0.14	<0.05	159	120	0.02	0.09	20	400	7.96	<1
P1A3	16Jul84	37	73	428	<0.01	<0.05	239	290	0.04	<0.01	22	650	7.48	<1
	19Jan85	90	80	454	0.79	0.13	275	277	0.05	0.09	19	700	7.51	>10
P1B1	16Jul84	34	83	396	<0.01	<0.05	183	312	0.11	0.20	22	530	7.50	<1
	20Jan85	108	80	438	0.55	<0.05	239	296	<0.02	0.36	18	495	7.40	1
P1C1	16Jul84	14	30	276	1.12	<0.05	174	250	0.21	0.67	23	375	6.32	1
	19Jan85	67	43	342	4.58	<0.05	212	230	<0.02	0.81	15	350	6.07	13
P1C2	16Jul84	34	18	814	0.19	<0.05	309	524	0.10	1.05	22	990	6.90	<1
	19Jan85	94	144	742	10.70	<0.05	403	442	0.05	1.02	18	1100	6.85	<1
P1C3	16Jul84	27	52	272	0.96	<0.05	178	256	<0.02	0.32	22	430	7.37	<1
	19Jan85	108	62	314	0.78	<0.05	189	212	0.02	0.16	18	435	7.28	<1
P1C4	16Jul84	1820	34	656	<0.01	<0.05	256	194	0.03	0.16	20	1040	7.65	<1
	19Jan85	208	148	540	1.28	<0.05	262	254	<0.02	0.24	18	1000	7.69	<1
P1D1	16Jul84	13	23	196	<0.01	<0.05	122	196	0.09	2.81	22	245	6.59	<1
	20Jan85	83	32	190	0.31	<0.05	88	127	0.02	6.34	18	190	6.55	<1
P1E1	16Jul84	13	22	140	<0.01	<0.05	109	170	0.06	0.56	22	275	6.78	312
	20Jan85	83	45	318	0.28	<0.05	164	212	0.02	1.25	17	340	6.71	<1
P1E2	16Jul84	27	61	188	<0.01	<0.05	109	220	0.03	1.14	21	345	7.74	<1
	20Jan85	90	52	226	0.12	<0.05	118	176	<0.02	0.59	19	360	7.61	<1
P1E3	16Jul84	24	52	230	0.19	<0.05	178	226	0.09	0.37	21	421	7.49	<1
	20Jan85	94	60	306	0.54	<0.05	205	216	0.03	0.24	18	445	7.55	<1

TABLE 3-7
(continued)
SUMMARY OF GROUND-WATER QUALITY ANALYSES FOR ATLANTIC BEACH/PINE KNOLL SHORES

Well ID	Sampling date	Sodium	Chlo-ride	Total dis-solved solids	Ammo-nia (mg/l as N)	Nitrate plus nitrite (mg/l as N)	Alkalin-ity (mg/l as $CaCO_3$)	Hardness (mg/l as $CaCO_3$)	MBAS (mg/l)	Ortho-phosphate (mg/l as P)	Temper-ature °C	Specific conductance (µmhos/cm)	pH (s.u.)	Fecal coliform (colonies per 100/ ml)
Pine Knoll Shores (cont'd) Transect P2														
P2A1	20Jan85	166	54	540	0.28	<0.05	348	364	0.02	0.50	19	760	7.23	<1
P2A2	20Jan85	427	460	1206	0.47	<0.05	372	465	<0.02	4.63	20	2000	7.46	<1
P2A3	20Jan85	420	328	892	1.35	<0.05	265	486	<0.02	1.71	20	1290	7.71	<1
P2B1	20Jan85	85	43	188	0.57	0.33	59	127	<0.02	0.78	17	270	7.65	<1
P2C1	20Jan85	98	48	306	0.28	<0.05	159	221	<0.02	0.50	-	-	6.86	<1
P2C2	20Jan85	126	141	648	5.00	<0.05	296	414	0.03	1.01	19	890	6.95	<1
P2C3	20Jan85	130	92	492	1.30	<0.05	219	329	0.04	0.96	19	720	7.31	2
P2C4	20Jan85	343	272	922	5.38	<0.05	414	207	0.02	0.12	19	1500	7.63	<1
P2D1	20Jan85	80	34	116	5.64	<0.05	55	207	0.02	3.76	19	200	6.74	<1
P2E1	20Jan85	84	71	390	0.22	<0.05	264	273	0.02	1.59	18	380	6.73	<1
P2E2	20Jan85	9	48	306	0.52	<0.05	284	519	0.02	1.87	19	440	7.45	<1
P2E3	20Jan85	1011	5044	10638	3.45	<0.05	282	1170	0.03	1.18	-	27500	7.61	<1

---

(1) All analyses are in milligrams per liter (mg/l) unless otherwise noted.

*Evidence of flooding at well site.

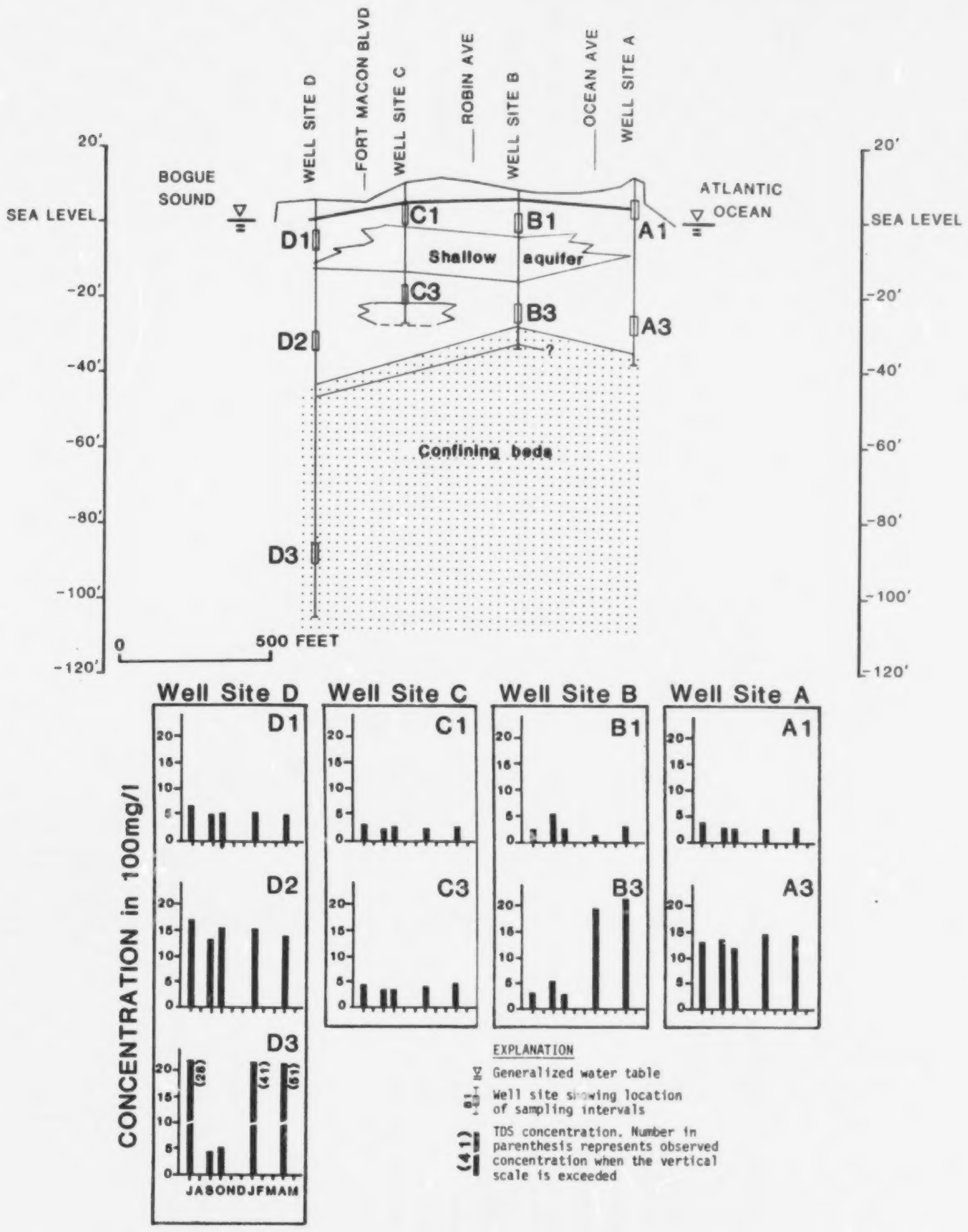


Figure 3-20. Variation in total dissolved solids concentration along Transect A1.

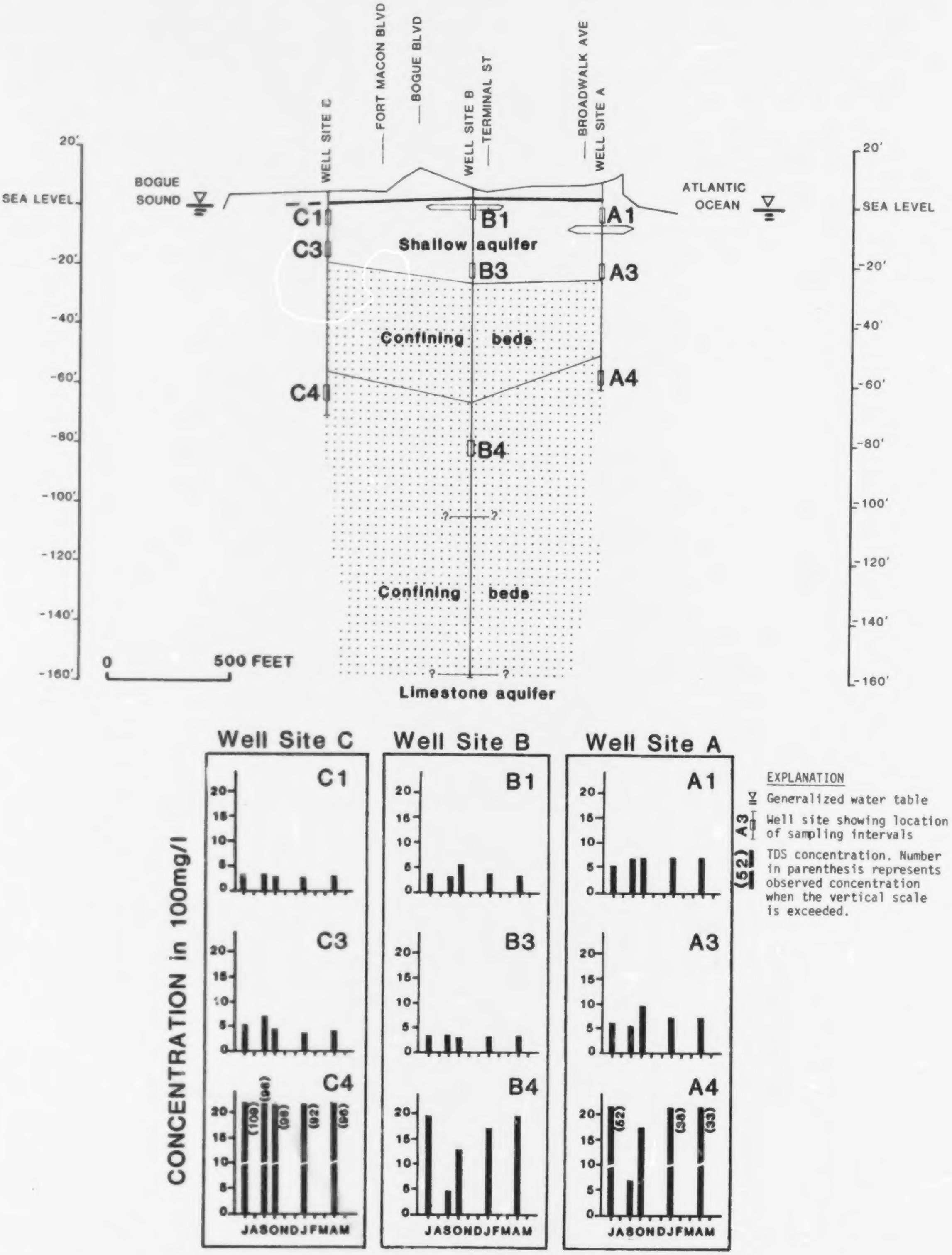


Figure 3-21. Variation in total dissolved solids concentration along Transect A2.

well site A1C shows no strong influence from saltwater intrusion. Freshwater generally exists in the shallow aquifer at Transect A2, but brackish to saline water was found in the underlying confining beds. At well A2A4, completed in the confining beds, total dissolved solids concentration at times exceeded the saline level. Definitions for fresh, brackish and saline waters are given in Section 3.1.2.5.1.

At Pine Knoll Shores, freshwater generally exists in the shallow aquifer. No strong influence from saltwater intrusion was evidenced along Transect P1. Elevated total dissolved solids contents were observed at two wells along Transect P2 (Table 3-7). The total dissolved solids content slightly exceeds the brackish concentration level at well P2A2 adjacent to the ocean. Saline water exists at well P2E3 adjacent to Bogue Sound.

3.2.2.5.2 Effects of Wastewater Disposal

Measured chemical properties of the ground water used to aid in defining the effects of wastewater disposal to the shallow aquifer included nitrate plus nitrite concentration (nitrate/nitrite), ammonia concentration, orthophosphate concentration, methylene blue active substances (MBAS) concentration, and fecal coliform concentration. Nitrate, nitrite, ammonia and orthophosphate are common nutrients present in wastewater. MBAS are substances used in detergents and that do not occur naturally in the environment. Fecal coliform are a group of bacteria which come from the intestines of mammals and may be found in wastewater and sometimes in storm water runoff.

Nitrate/nitrite and ammonia, reported in mg/l as nitrogen (N), were detected in ground water at each of the transects in the Atlantic Beach/Pine Knoll Shores study area (Table 3-7). Nitrate/nitrite concentrations showed no obvious trend during the study period except that significantly elevated nitrate/nitrite concentrations were measured at most wells in Atlantic Beach following hurricane Diane. Ammonia concentrations typically increased with depth, with the exception of well sites A1D and P1C, where most high readings were obtained near the surface of the aquifer. Variations in nitrate/nitrite and ammonia concentrations along Transect A1 and A2 are shown in Figures 3-22, 3-24 and 3-23, 3-25, respectively.

Nitrate, nitrite and ammonia are contaminants which are frequently found in ground water. The presence of these constituents in the shallow ground water could, therefore, be indicative of the impact of wastewater disposal. The highest observed levels of nitrate/nitrite and ammonia were 1.24 mg/l and 17.20 mg/l, respectively. The drinking water standard for nitrates is 10 mg/l as nitrogen (N). There are no drinking water standards for ammonia.

Orthophosphates, reported in mg/l as phosphorus (P), were also detected in ground water along all transects in Atlantic Beach and Pine Knoll Shores (Table 3-7). Along Transect A1, higher concentrations appear to be at depth, with the exception of well site A1D, where the highest concentrations are nearer the surface. Along Transect A2, high and low concentrations appear equally distributed with depth. Along Pine

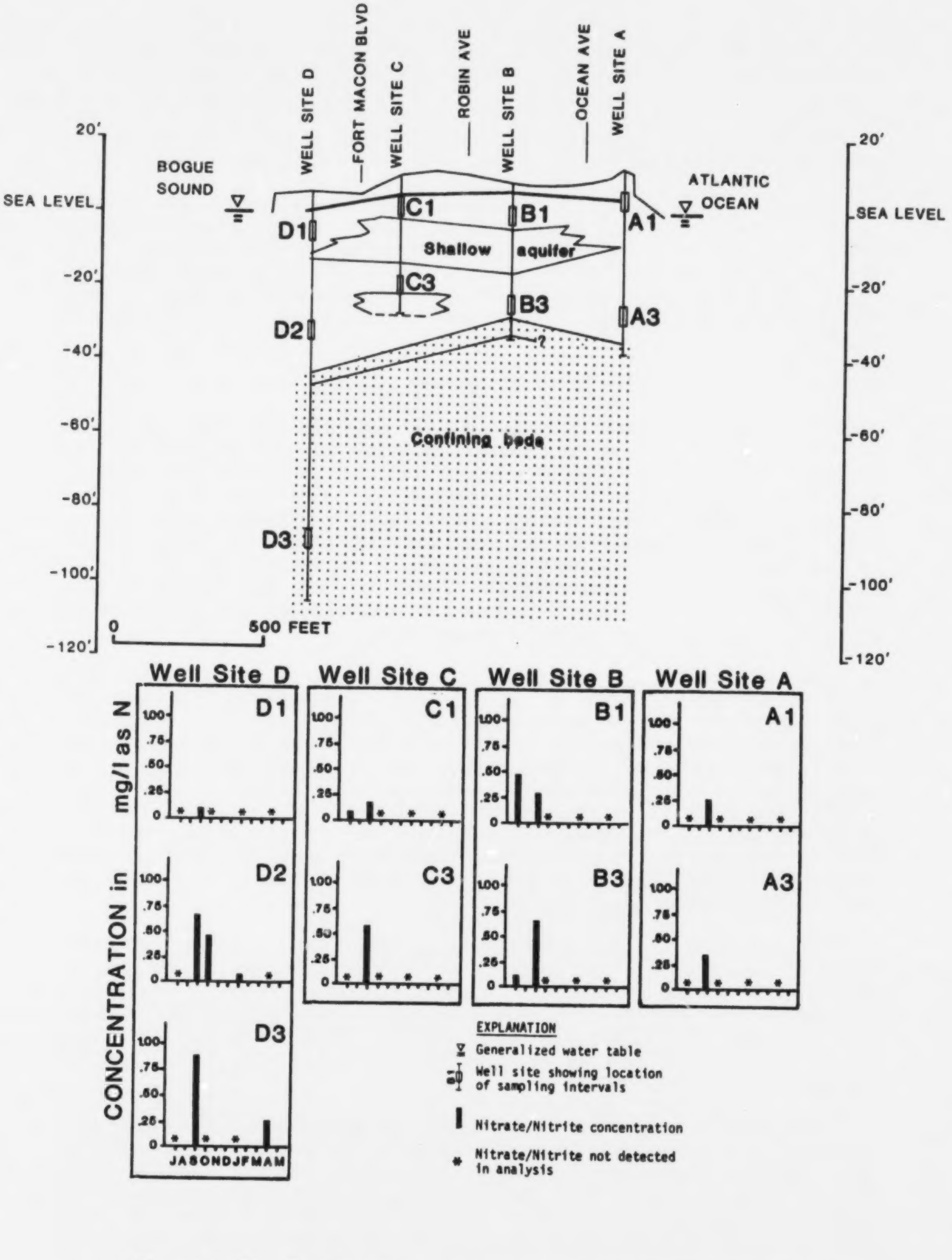


Figure 3-22. Variation in nitrate plus nitrite concentration along Transect A1.

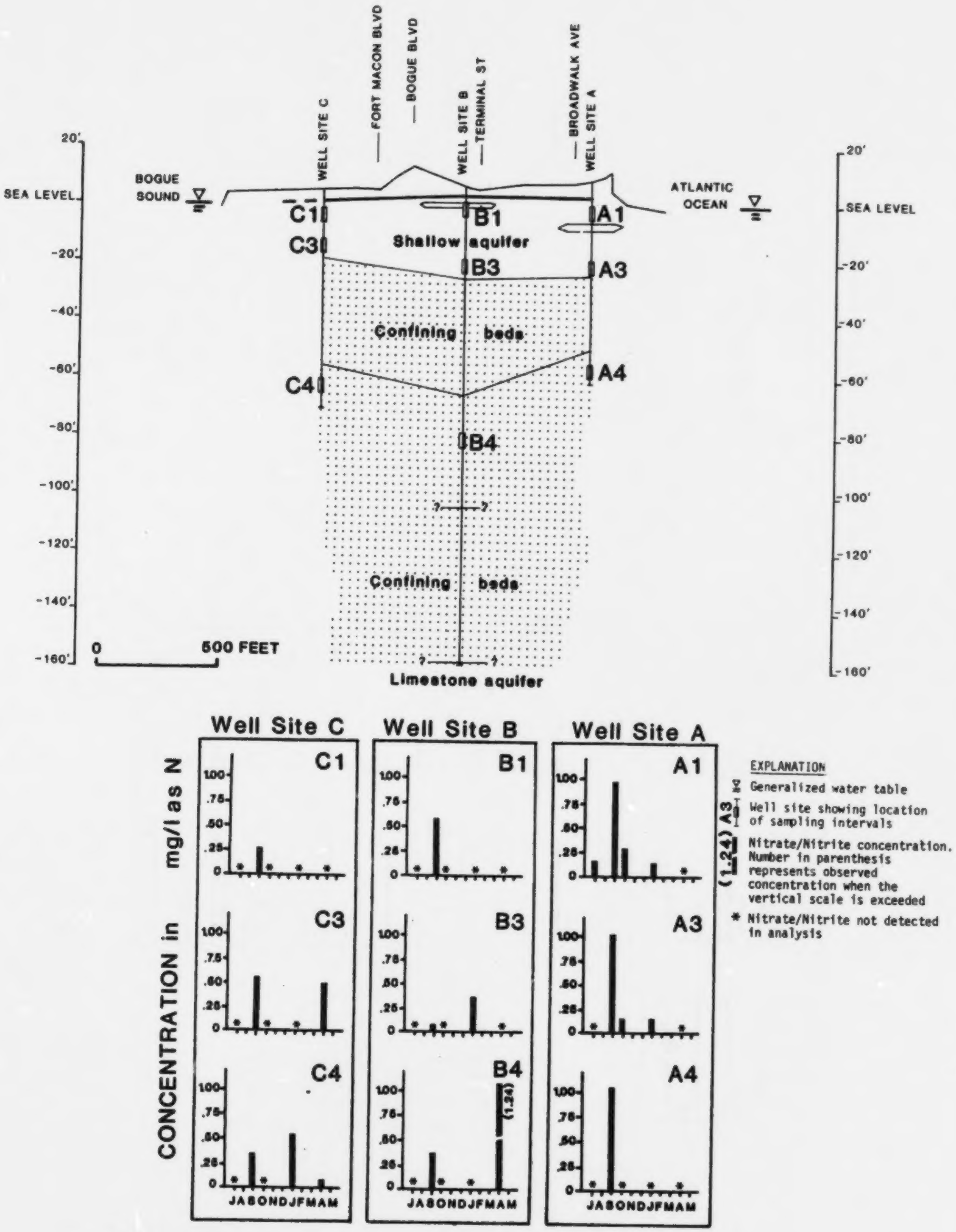


Figure 3-23. Variation in nitrate plus nitrite concentration along Transect A2.

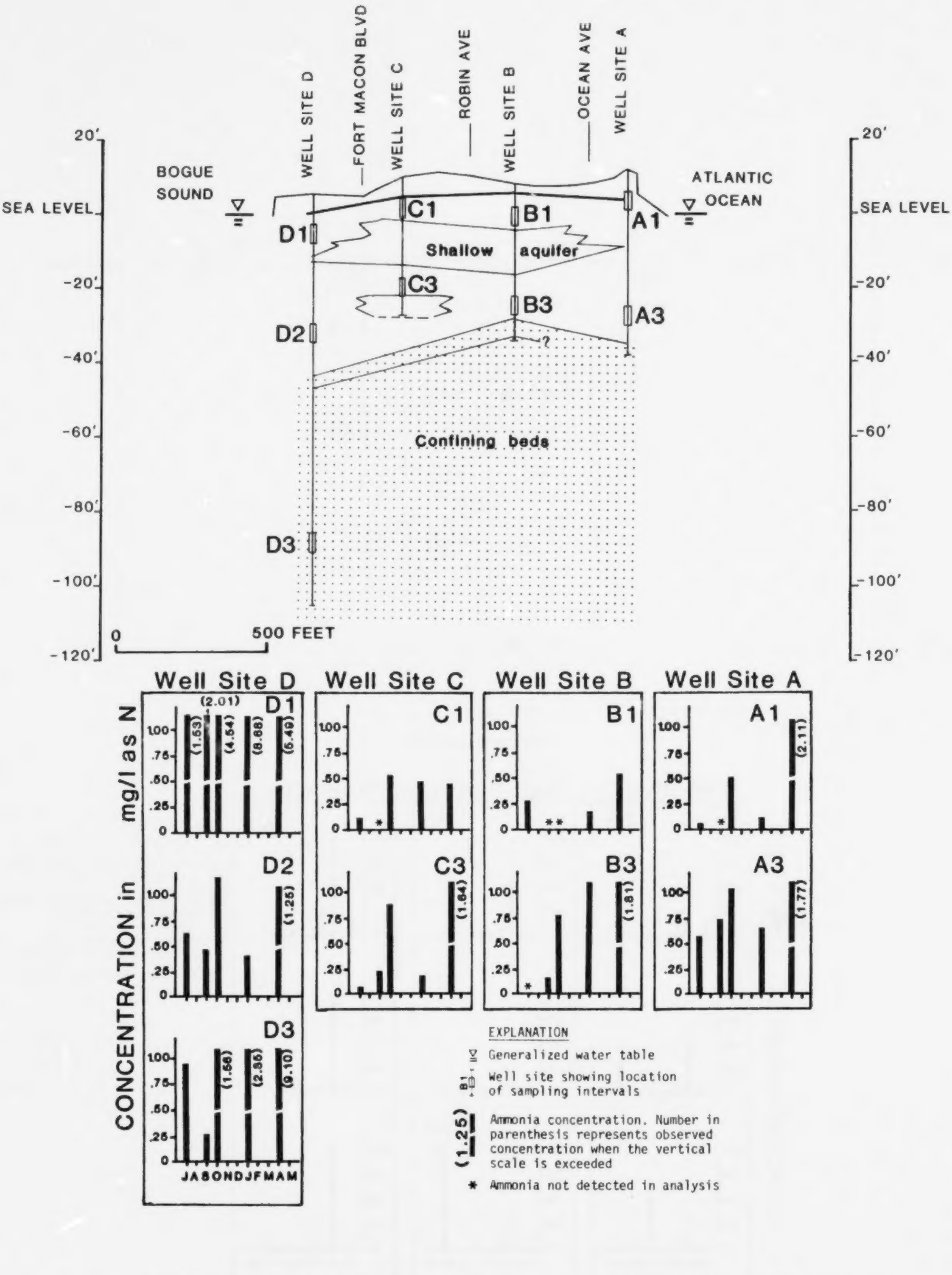


Figure 3-24. Variation in ammonia concentration along Transect A1.

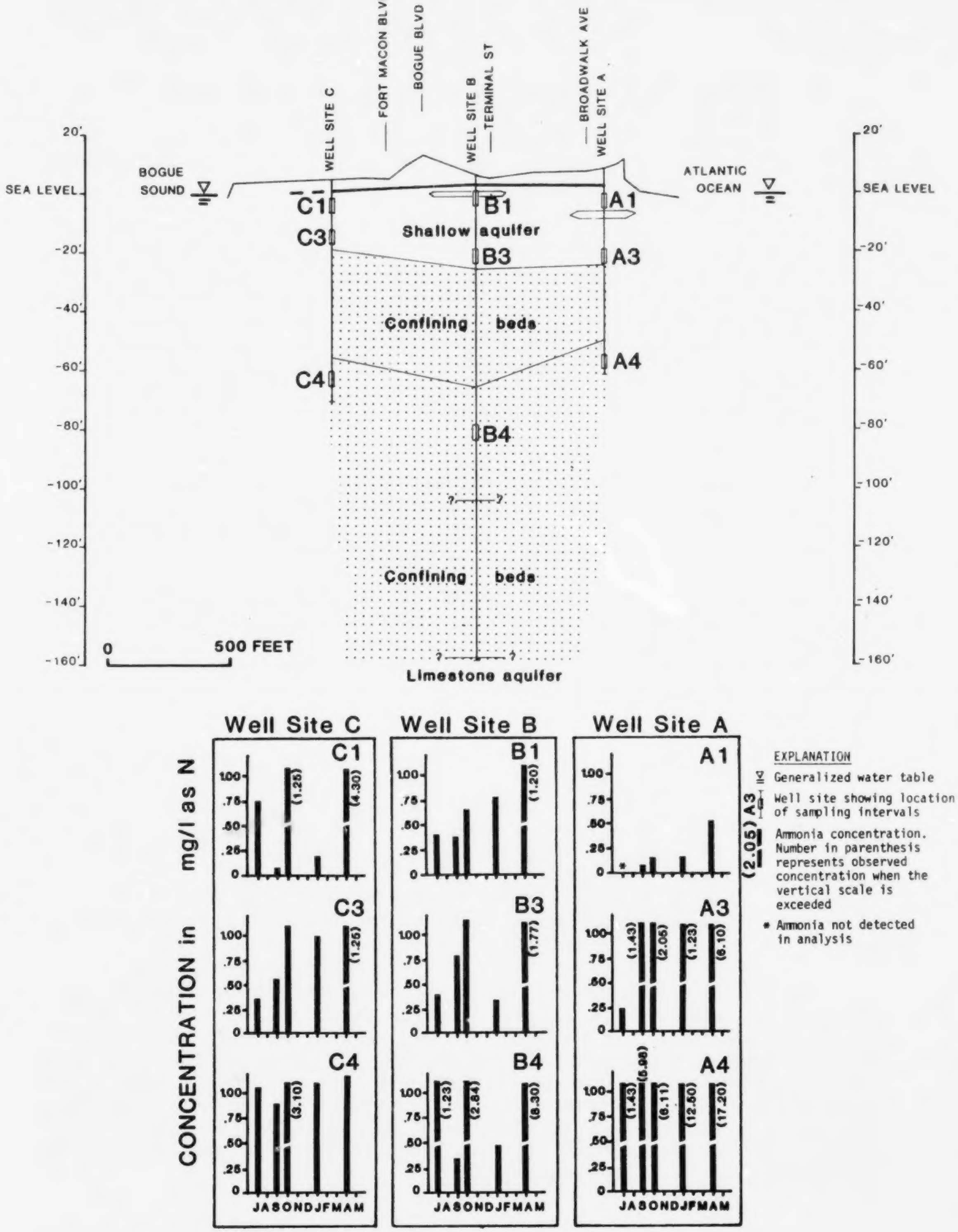


Figure 3-25. Variation in ammonia concentration along Transect A2.

Knoll Shores transects, the highest orthophosphate concentrations appear to be at an intermediate depth, with the lowest readings occurring deeper in the aquifer. Variations in orthophosphate concentrations along Transects A1 and A2 are shown in Figures 3-26 and 3-27, respectively.

The presence of phosphorous compounds in the ground water is typically a result of wastewater disposal. The usual sources for phosphorous are organic waste products and phosphate detergent residues. The highest observed level of orthophosphate was 6.34 mg/l. There are no drinking water standards for orthophosphates.

MBAS were detected at most well sites during the study but were found more consistently and generally in higher concentrations during the July 1984 and April 1985 samplings (Table 3-7). These observations probably reflect the impact on the shallow aquifer resulting from increased wastewater disposal during the spring and summer months. The presence of MBAS in the deepest wells indicates that wastewater has penetrated the entire thickness of the shallow aquifer and has also penetrated the confining beds underlying the aquifer. Variations in MBAS concentrations along Transects A1 and A2 are shown in Figures 3-28 and 3-29, respectively.

The highest MBAS concentration detected at Atlantic Beach and Pine Knoll Shores was 0.26 mg/l. The recommended secondary drinking water standard for MBAS is 0.50 mg/l. The source of MBAS in wastewater is synthetic foaming agents present in modern detergents.

Fecal coliform were found in 40 of the 126 ground-water samples collected in Atlantic Beach and Pine Knoll Shores. The fecal coliform detected in 27 of these samples may have reflected contamination of those wells by surface flooding. Fecal coliform detected in the remaining 13 samples are probably reflecting the presence of domestic wastewater in the ground water.

Very high levels of fecal coliform were noted at well site A2C in July 1984 and at well sites A1D, A2B and A2C in September and October of 1984 (Table 3-7). There was evidence that well site A2C had been flooded prior to both the July and September samplings and that well sites A1D and A2B were flooded prior to the September sampling. The high fecal coliform counts at these well sites are probably related to the flooding. Steps were taken to prevent further contamination of the well sites prior to continued sampling, although residue contamination was evidenced at most of the well sites in October.

Fecal coliform, probably resulting from wastewater disposal, were detected at some well sites in Atlantic Beach and Pine Knoll Shores during the course of the study (Table 3-7). Fecal coliform were detected in water samples from wells A1A1, A1A3, A1C1, A1C3 and P1E1 in July 1984 and in water samples from wells P1A3 and P1C1 in January 1985. The highest fecal coliform count observed, outside those at well sites A1D, A2B and A2C, was 312 col/100 ml in July 1984 at well P1E1 in Pine Knoll Shores. Variations in fecal coliform along Transects A1 and A2 are shown in Figures 3-30 and 3-31, respectively.

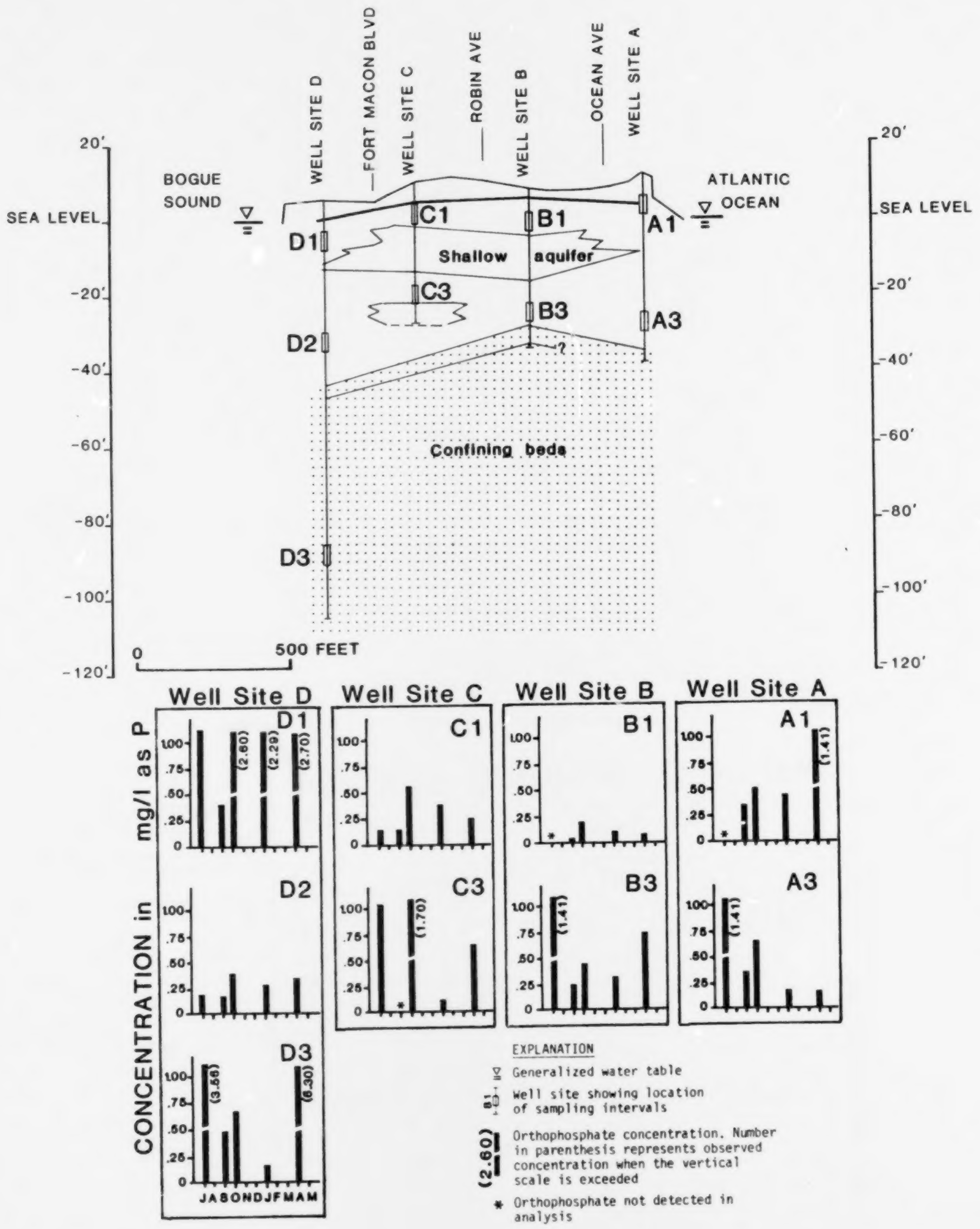


Figure 3-26. Variation in orthophosphate concentration along Transect A1.

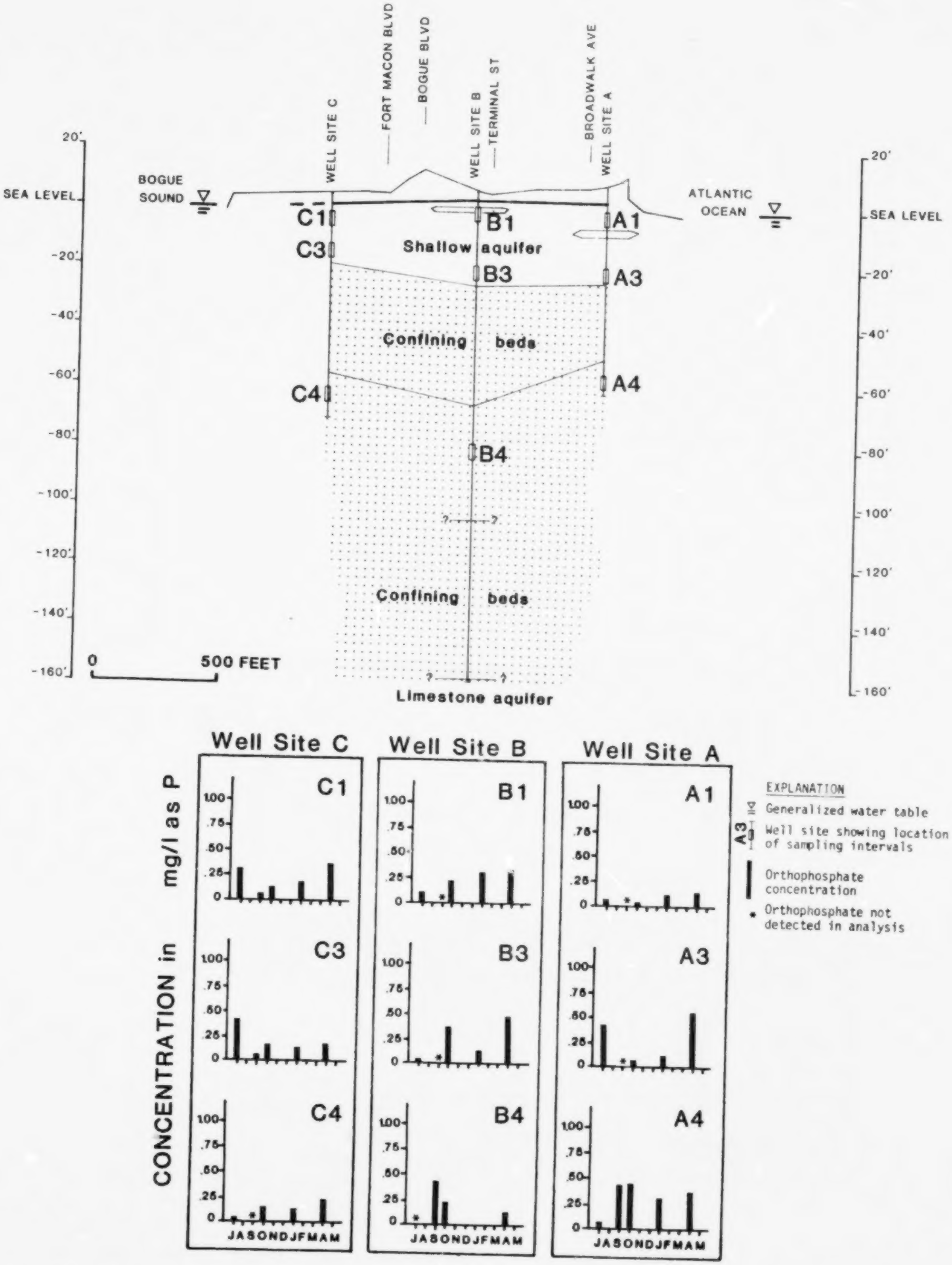


Figure 3-27. Variation in orthophosphate concentration along Transect A2.

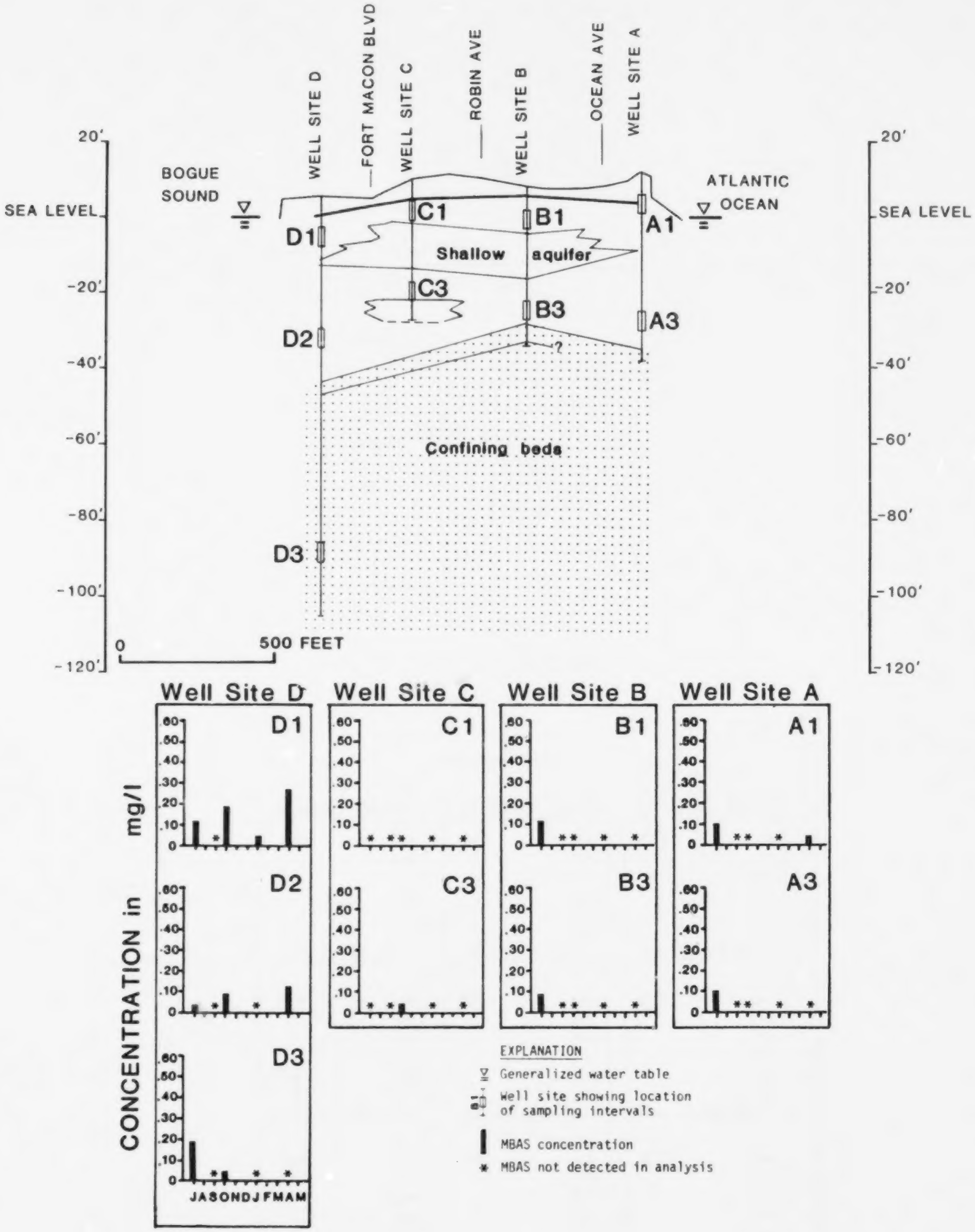


Figure 3-28. Variation in MBAS concentration along Transect A1.

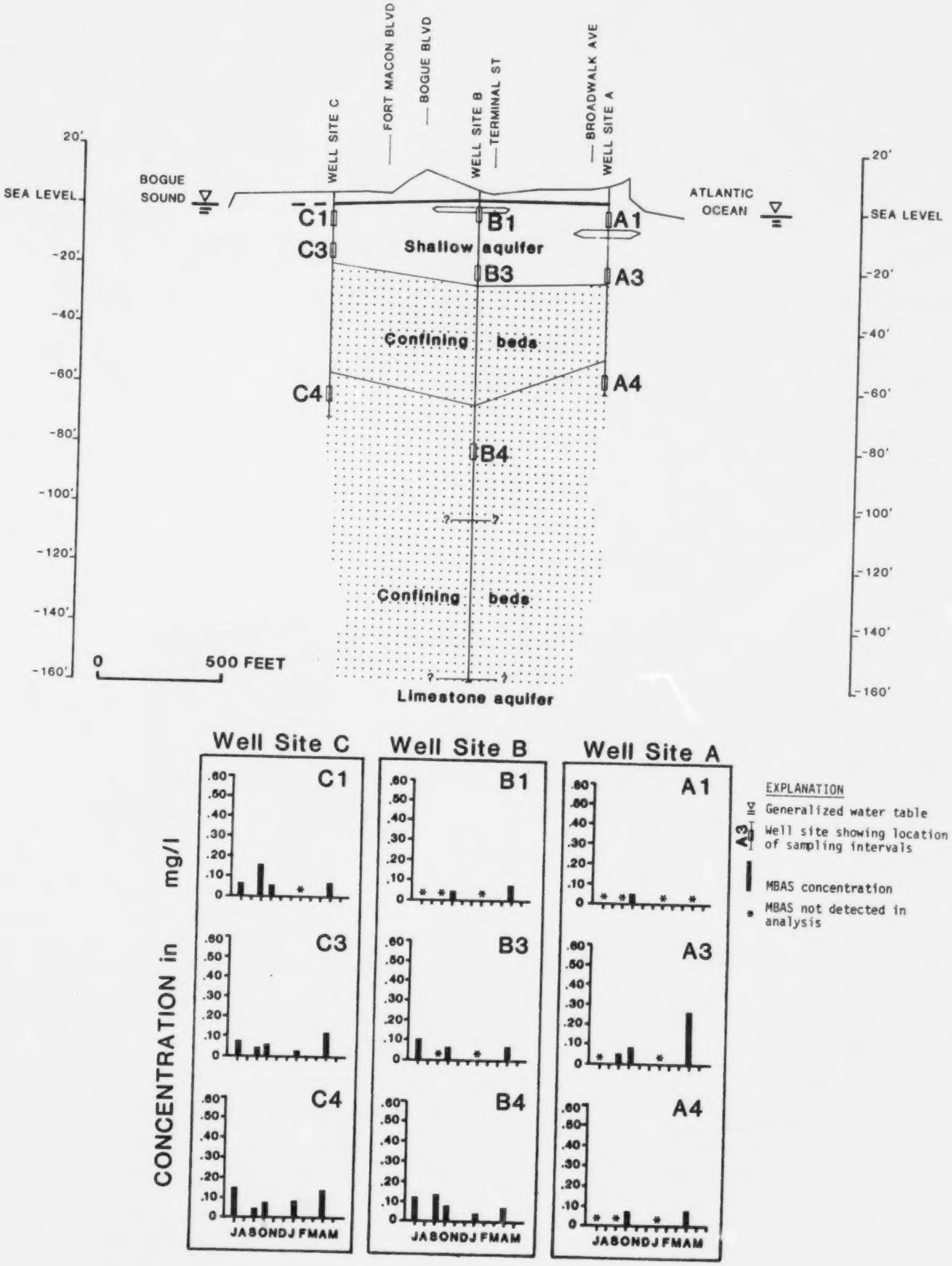


Figure 3-29. Variation in MBAS concentration along Transect A2.

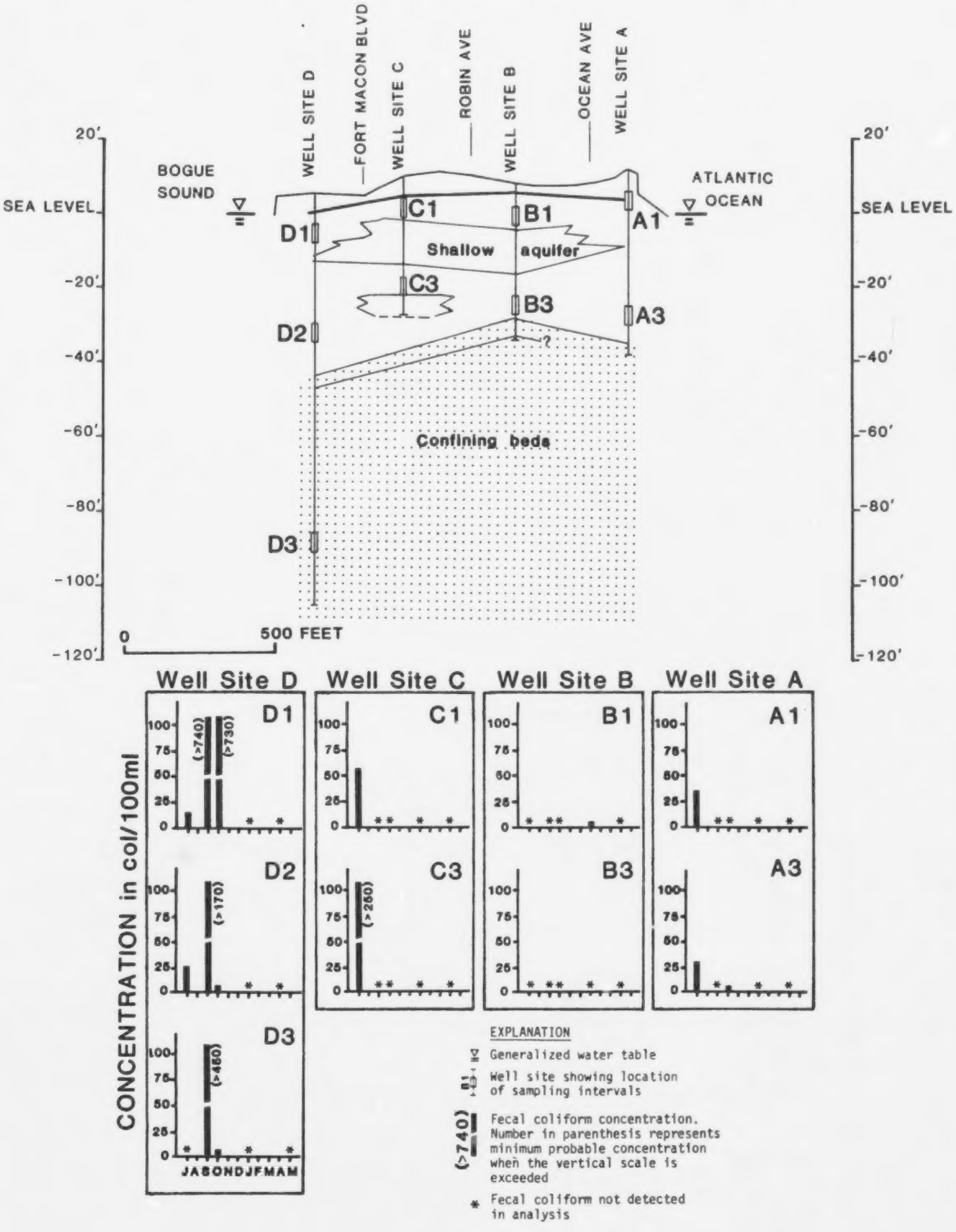


Figure 3-30. Variation in fecal coliform concentration along Transect A1.

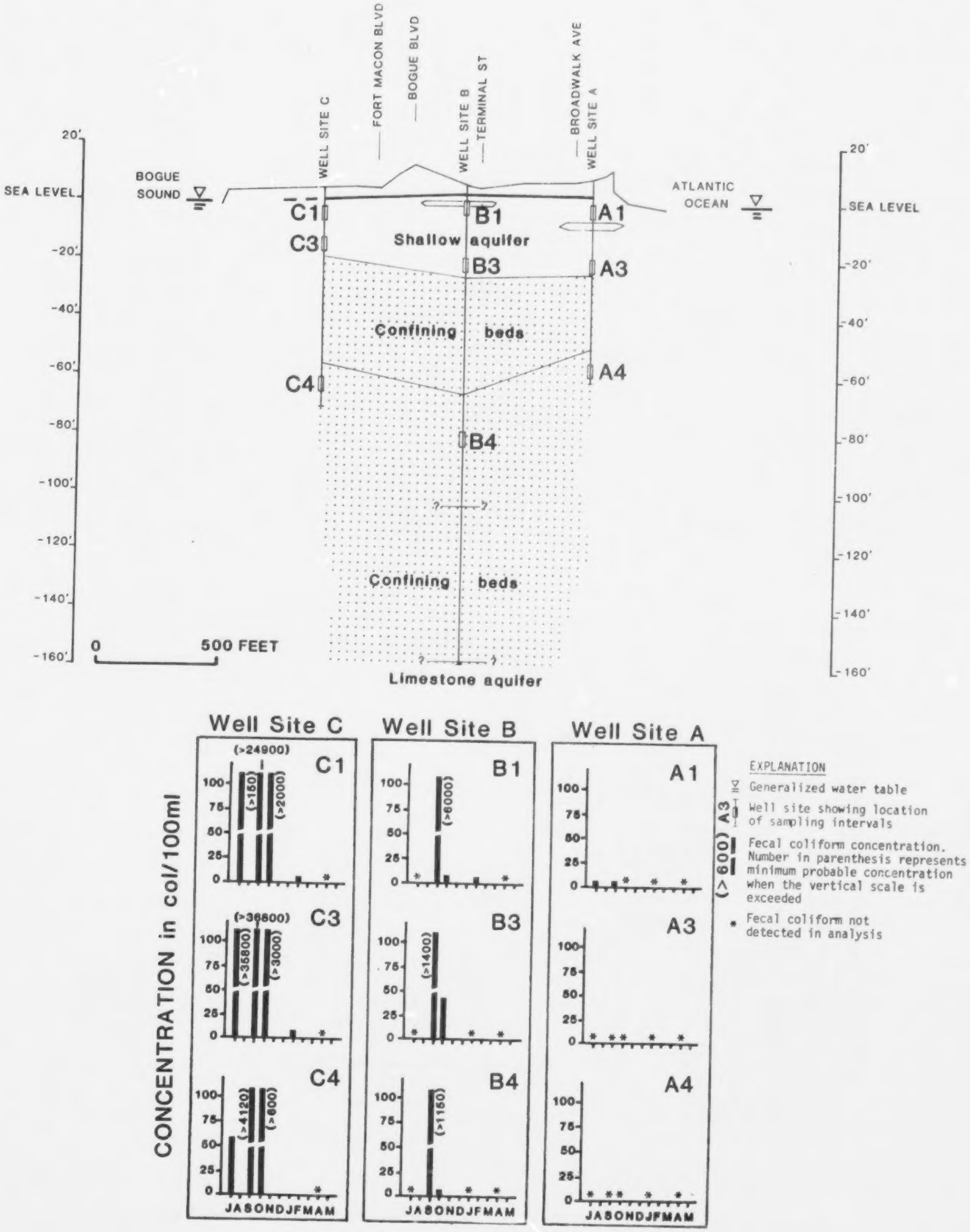


Figure 3-31. Variation in fecal coliform concentration along Transect A2.

Changes in ground-water quality observed between July and September 1984 are at least partially due to the impacts of hurricane Diane. Increased nitrate/nitrite and decreased orthophosphate and MBAS levels generally observed at the water-table surface are probably due to the heavy rainfall received in October. Changes in water quality parameters deeper in the aquifer, however, may be the results of previous impacts on the shallow aquifer. A period of months are probably required for ground-water flow to penetrate from the water-table surface to deeper parts of the aquifer.

The impact of large wastewater volumes on ground-water quality can be readily seen at well site A1D. A drainfield at this location serves a large condominium complex. Approximately two-thirds of the water used along Transect A1 is recharged to the aquifer by this drainfield. Ammonia, nitrate/nitrite, MBAS and orthophosphate concentrations in the ground water at this site are among the highest observed during the study. However, nitrate/nitrite and MBAS concentrations do not exceed established drinking water standards. Fecal coliform are present in the wells at this site, but these results are suspect due to the well site's susceptability to flooding.

Alkalinity and hardness of the ground water were measured as overall indicators of water quality. Alkalinity is a measure of the carbonate and bicarbonate ions in the water, with maximum levels of approximately 400 mg/l as calcium carbonate ($CaCO_3$) considered to represent no health problem. Hardness is a measure of the amount of calcium, magnesium and iron in the water. A strong relationship between these parameters and saltwater intrusion into the aquifer was observed from the data (Table 3-7).

Alkalinity generally increased with depth in the shallow aquifer, although exceptions can be noted (Table 3-7). The alkalinity of the water typically ranged from 100 to 200 mg/l at the water-table surface, with values at well sites A1D and A2C as high as 450 mg/l. Alkalinity levels below the water-table surface ranged as high as 400 mg/l in Pine Knoll Shores and as high as 550 mg/l in Atlantic Beach. The alkalinity of the water at most sampling points is in the range of that generally found in ground waters.

The hardness of the water also generally increased with depth in the aquifer, although the data are not consistent, and many exceptions exist (Table 3-7). Hardness was generally 150 to 300 mg/l as $CaCO_3$ at the water-table surface and 300 to 500 mg/l as $CaCO_3$ at the base of the aquifer. Water is generally considered to be hard water when the hardness exceeds 150 mg/l, and very hard when in excess of 300 mg/l as $CaCO_3$. Since hardness in water can be easily removed with treatment, and because hardness concentrations in water have not proven to be health-related, no criterion exists for raw waters used for public water supply.

3.2.3 Summary of Hydrogeologic Setting for the Atlantic Beach/Pine Knoll Shores Study Area

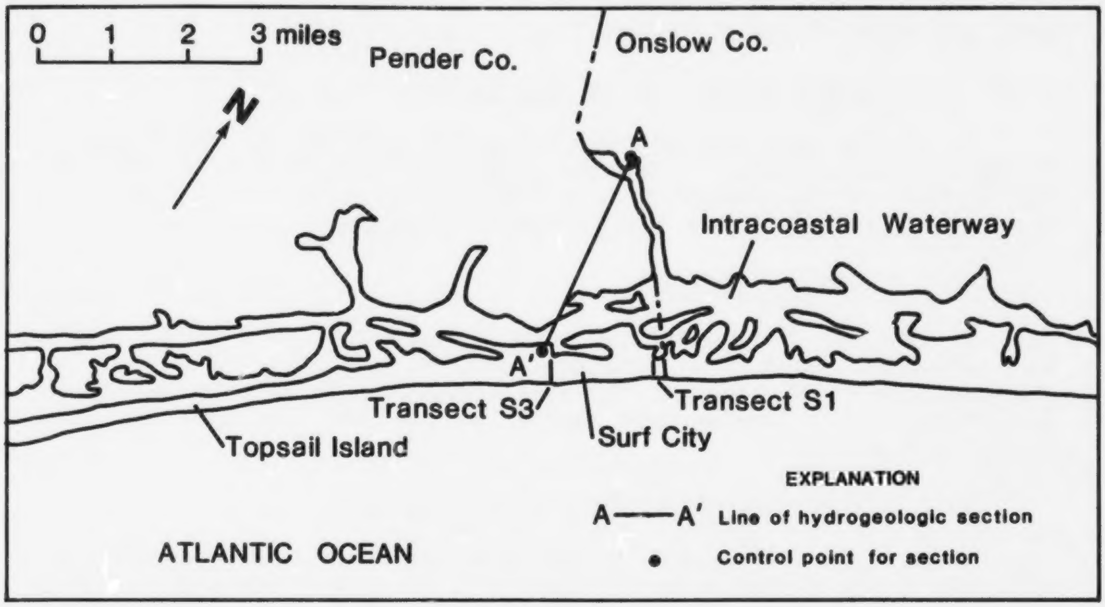
The hydrogeology at Atlantic Beach and Pine Knoll Shores was studied to identify the movement of ground water in the shallow aquifer underlying Bogue Banks, to identify the components of recharge to the aquifer and their magnitude, and to identify the existing quality of ground water underlying the island. The results of this study can be summarized as follows:

- Bogue Banks is underlain by three aquifers, two of which are known to contain freshwater.
- The shallow aquifer, consisting of fine to medium sand with lenses of silty fine sand and organic silt, extends downward from land surface to depths of 25 to 65 feet, and is separated from the deeper aquifers by beds of silt and clay.
- Ground-water movement in the shallow aquifer is generally away from the central part of Bogue Banks toward discharge points in the ocean and the sound. Ground-water flow velocities at the transects vary from less than 0.1 to about 1.6 feet per day.
- Tidal fluctuations have little or no influence on ground-water levels outside the immediate vicinity of the ocean and the sound.
- Precipitation and wastewater are both important sources of recharge to the shallow aquifer at Atlantic Beach.
- Precipitation is the major source of recharge to the shallow aquifer at Pine Knoll Shores and wastewater is a minor source of recharge.
- The shallow aquifer generally contains freshwater but the underlying confining beds in Atlantic Beach are known to contain brackish water.
- Disposal of wastewater into the shallow aquifer has had some impact on water quality in the shallow aquifer.

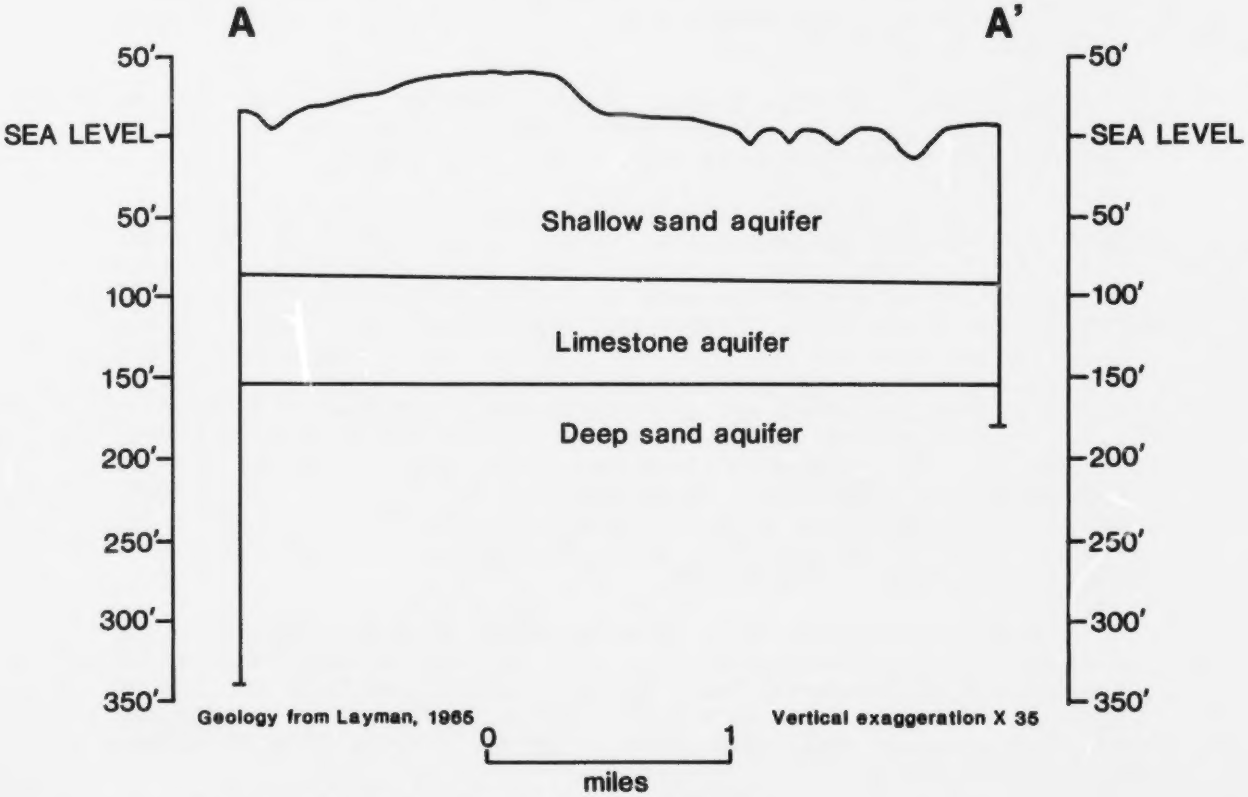
3.3 Hydrogeology of the Surf City Study Area

3.3.1 General Hydrogeology

The ground-water system in the Surf City area has been grouped into three aquifers (Layman, 1965). These aquifers are the shallow sand aquifer, the limestone aquifer and the deep sand aquifer. The shallow sand aquifer generally consists of fine sand and shells and is 30 to 50 feet thick in the study area. The limestone aquifer underlies the shallow sand aquifer and is as much as 70 feet thick in the area. The deep sand aquifer, of undetermined thickness, lies beneath the limestone aquifer. A generalized hydrogeologic cross-section that extends from the mainland to Topsail Island is shown in Figure 3-32.


0 1 2 3 miles
Pender Co.
Onslow Co.
N
A
Intracoastal Waterway
A'
Transect S3
Transect S1
Surf City
Topsail Island
EXPLANATION
A——A' Line of hydrogeologic section
● Control point for section
ATLANTIC OCEAN

a. Location map for generalized hydrogeologic cross-section.


A
A'
50'
SEA LEVEL
50'
100'
150'
200'
250'
300'
350'
Shallow sand aquifer
Limestone aquifer
Deep sand aquifer
Geology from Layman, 1965
Vertical exaggeration X 35
0
1
miles

b. Generalized hydrogeologic cross-section.

Figure 3-32. Generalized hydrogeologic cross-section for the Surf City study area.

Freshwater can be obtained from all three aquifers on the mainland about six miles northeast of Surf City.

3.3.2 Hydrogeology of the Shallow Sand Aquifer

The shallow sand aquifer was studied for this report. This aquifer is the one most impacted by the use of on-site systems for the treatment and disposal of wastewater. Data collected from wells drilled along Transects S1 and S3 (Figure 3-32) formed the basis for the study.

3.3.2.1 Geologic Setting

The shallow sand aquifer consists of fine sands and shells. Sandy silt and clay, which occur between 30 and 40 feet below land surface, form the base of the aquifer. Geologic cross-sections showing the nature and extent of the shallow sand aquifer in the Surf City area are presented in Figure 3-33.

3.3.2.2 Ground-Water Occurrence a[illegible]ovement

Ground water is present in the pore spaces of the unconsolidated saturated deposits that underlie Topsail Island. The intergranular pore spaces in the sands serve as the storage space for water in the shallow sand aquifer and as pathways for water movement. The pore spaces in the sandy silt and clay confining beds also serve to store water. However, those pore spaces are extremely small, making movement of water through these deposits difficult.

Ground water is also present in the limestone that underlies the unconsolidated deposits. Interconnected joints, fractures and solution openings in the limestone store and transmit water freely.

Ground-water movement under Topsail Island was variable during the study. Freshwater movement along Transect S1 was generally toward the Intracoastal Waterway, but occasionally was toward the ocean. Brackish water movement was toward the ocean at times and toward the Intracoastal Waterway at other times. Freshwater movement along Transect S3 was generally downward and away from the central part of the island toward discharge points in the ocean and the Intracoastal Waterway. Brackish and saline water movement was generally downward and toward the mainland in the upper portion of the limestone aquifer along this transect; however, vertical movement of the deeper saline water was upward at times and downward at other times. Ground-water flow patterns in August 1984, which are representative of summer conditions, are shown in Figure 3-34. Flow patterns in February 1985, which are representative of winter conditions, are shown in Figure 3-35.

Saltwater intrusion has a definite effect on water movement in the shallow aquifer. Ground-water flow patterns were defined based on the distribution of freshwater heads and environmental heads in the aquifer system. Freshwater heads were used to define horizontal flow directions and environmental heads were used to define vertical flow directions (Lusczynski, 1961).

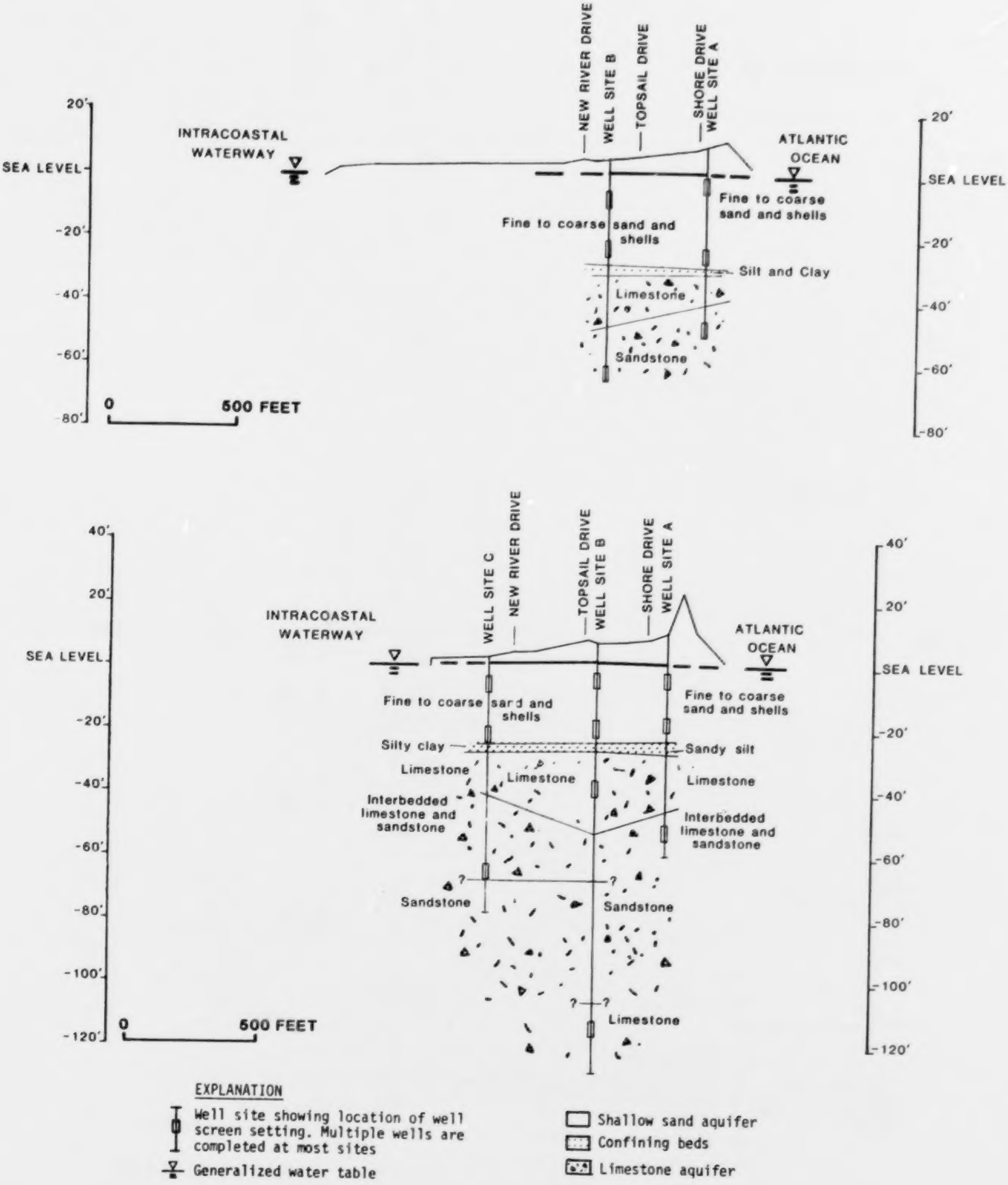
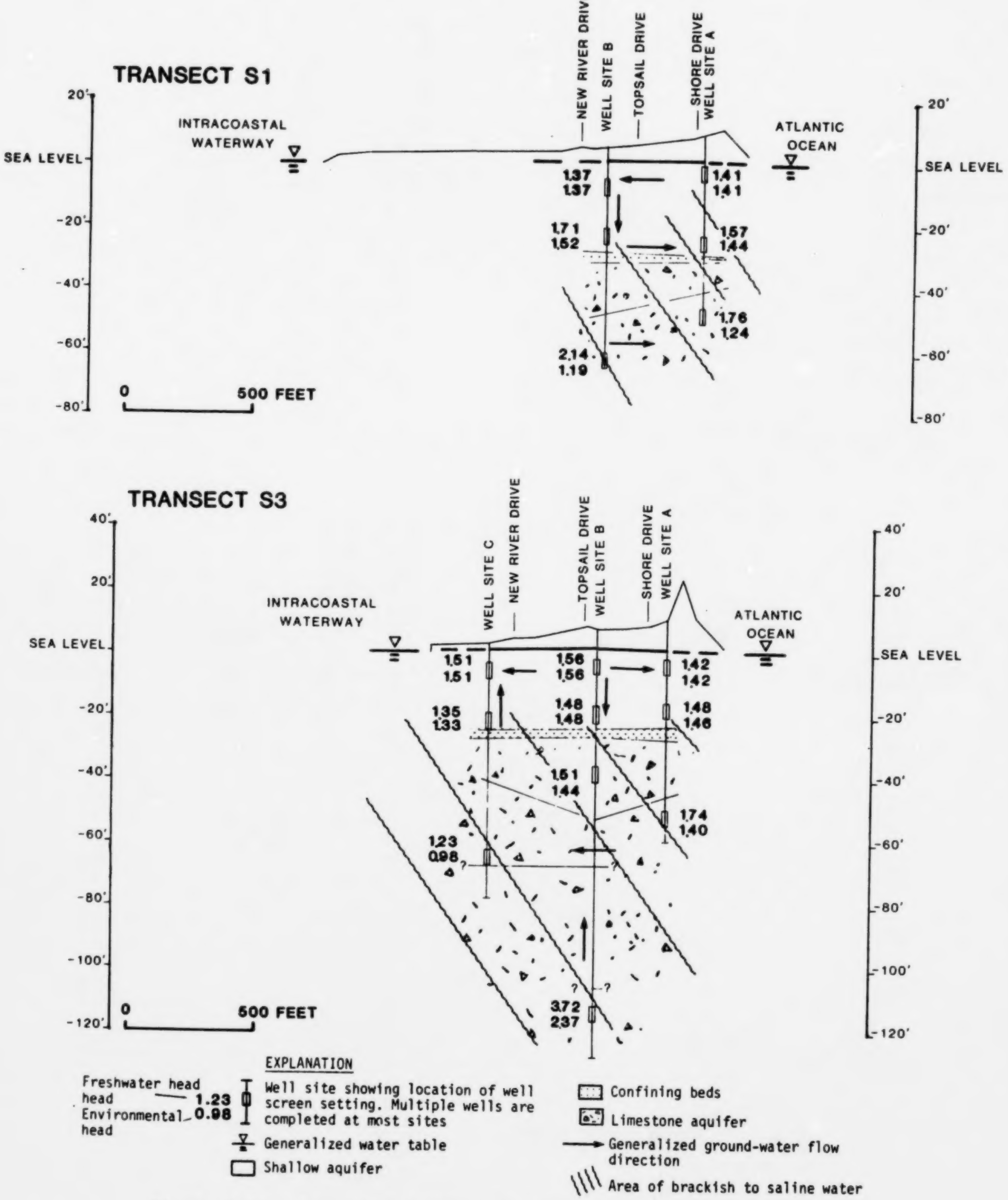

NEW RIVER DRIVE
WELL SITE B
TOPSAIL DRIVE
SHORE DRIVE
WELL SITE A
INTRACOASTAL WATERWAY
ATLANTIC OCEAN
20'
SEA LEVEL
-20'
-40'
-60'
-80'
Fine to coarse sand and shells
Fine to coarse sand and shells
Silt and Clay
Limestone
Sandstone
0
500 FEET
WELL SITE C
NEW RIVER DRIVE
TOPSAIL DRIVE
WELL SITE B
SHORE DRIVE
WELL SITE A
INTRACOASTAL WATERWAY
ATLANTIC OCEAN
40'
20'
SEA LEVEL
-20'
-40'
-60'
-80'
-100'
-120'
Fine to coarse sand and shells
Fine to coarse sand and shells
Silty clay
Sandy silt
Limestone
Limestone
Limestone
Interbedded limestone and sandstone
Interbedded limestone and sandstone
Sandstone
Sandstone
Limestone
?
0
500 FEET
EXPLANATION
Well site showing location of well screen setting. Multiple wells are completed at most sites
Generalized water table
Shallow sand aquifer
Confining beds
Limestone aquifer

Figure 3-33. Hydrogeologic cross-sections for the shallow sand aquifer at Surf City.



TRANSECT S1
20'
SEA LEVEL
-20'
-40'
-60'
-80'
INTRACOASTAL WATERWAY
NEW RIVER DRIVE
WELL SITE B
TOPSAIL DRIVE
SHORE DRIVE
WELL SITE A
ATLANTIC OCEAN
1.37
1.37
1.41
1.41
1.71
1.52
1.57
1.44
1.76
1.24
2.14
1.19
0
500 FEET
20'
SEA LEVEL
-20'
-40'
-60'
-80'
TRANSECT S3
40'
20'
SEA LEVEL
-20'
-40'
-60'
-80'
-100'
-120'
INTRACOASTAL WATERWAY
WELL SITE C
NEW RIVER DRIVE
TOPSAIL DRIVE
WELL SITE B
SHORE DRIVE
WELL SITE A
ATLANTIC OCEAN
1.51
1.51
1.56
1.56
1.42
1.42
1.35
1.33
1.48
1.48
1.48
1.46
1.51
1.44
1.74
1.40
1.23
0.98
?
?
?
3.72
2.37
0
500 FEET
40'
20'
SEA LEVEL
-20'
-40'
-60'
-80'
-100'
-120'
EXPLANATION
Freshwater head
head 1.23
Environmental head 0.98
Well site showing location of well screen setting. Multiple wells are completed at most sites
Generalized water table
Shallow aquifer
Confining beds
Limestone aquifer
Generalized ground-water flow direction
Area of brackish to saline water

Figure 3-34. Generalized flow directions in the shallow sand aquifer at Surf City on August 22, 1984.

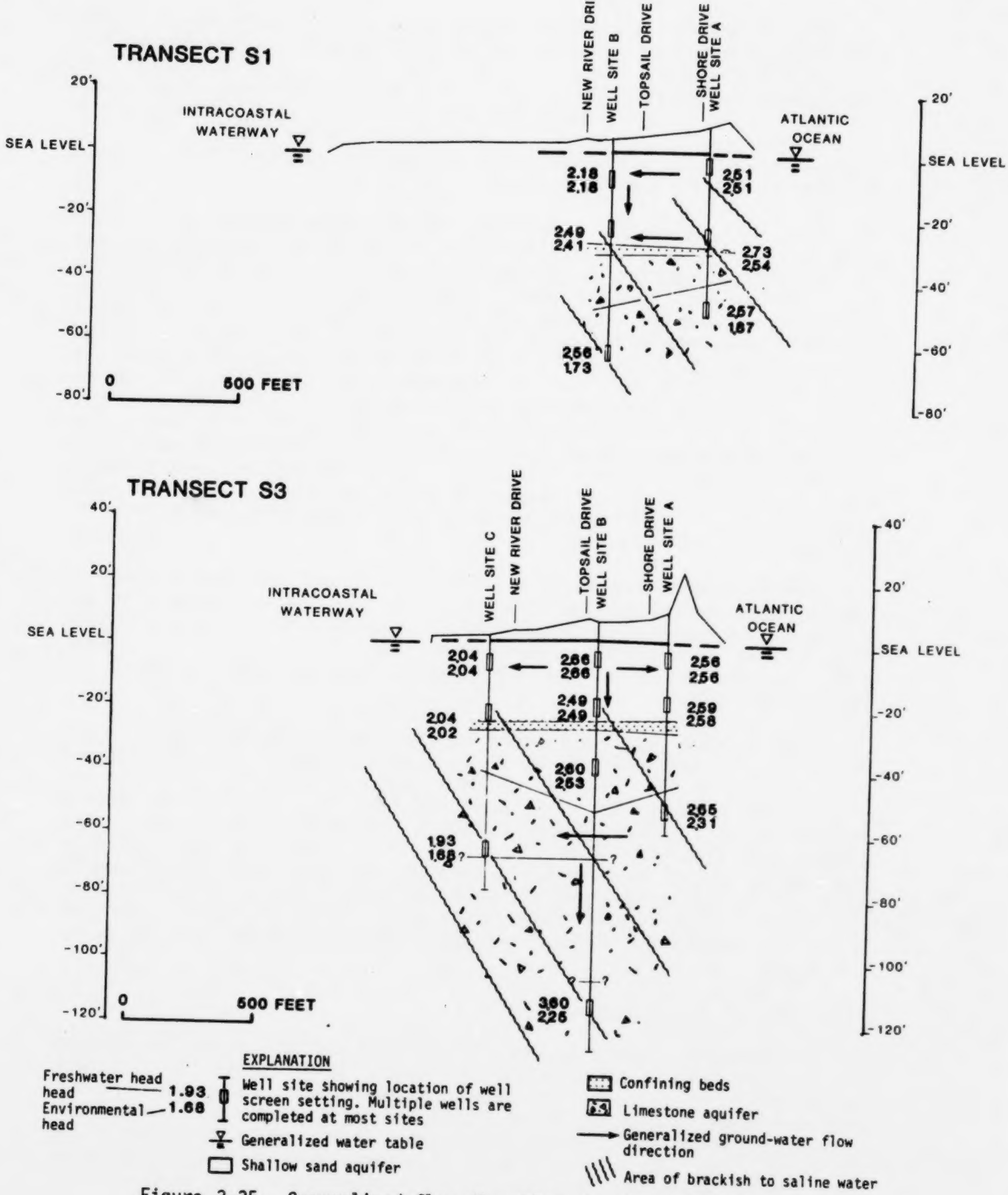

TRANSECT S1
20'
SEA LEVEL
-20'
-40'
-60'
-80'
0
500 FEET
INTRACOASTAL WATERWAY
NEW RIVER DRIVE
WELL SITE B
TOPSAIL DRIVE
SHORE DRIVE
WELL SITE A
ATLANTIC OCEAN
2.18
2.18
2.51
2.51
2.49
2.41
2.73
2.54
2.57
1.87
2.56
1.73
TRANSECT S3
40'
20'
SEA LEVEL
-20'
-40'
-60'
-80'
-100'
-120'
0
500 FEET
INTRACOASTAL WATERWAY
WELL SITE C
NEW RIVER DRIVE
TOPSAIL DRIVE
WELL SITE B
SHORE DRIVE
WELL SITE A
ATLANTIC OCEAN
2.04
2.04
2.66
2.66
2.56
2.56
2.49
2.49
2.04
2.02
2.59
2.58
2.60
2.53
2.65
2.31
1.93
1.68
?
?
?
3.60
2.25
EXPLANATION
Freshwater head
head
1.93
Environmental
head
1.68
Well site showing location of well screen setting. Multiple wells are completed at most sites
Generalized water table
Shallow sand aquifer
Confining beds
Limestone aquifer
Generalized ground-water flow direction
Area of brackish to saline water

Figure 3-35. Generalized flow directions in the shallow sand aquifer at Surf City on February 12-13, 1985.

Significant recharge events would cause changes in freshwater movement along Transect S3. During October 1984 and again during March 1985, freshwater movement along this transect was generally toward the Intracoastal Waterway. There was little movement of freshwater toward the ocean. The October change followed hurricane Diane, which occurred in September, while the March change followed a heavy February rainfall. Within one month of the observed changes, freshwater flow patterns returned to those normally observed.

The flow velocity through the shallow sand aquifer varied considerably during the study. There was little or no freshwater movement in the shallow aquifer at Transect S1 during early November 1984 and again during late January 1985. The freshwater velocity toward the Intracoastal Waterway exceeded 1.5 ft/day between sites S3B and S3C in September immediately following hurricane Diane and averaged about 0.7 ft/day during the study (Table 3-8). The freshwater velocity toward the ocean between sites S3B and S3A averaged about 0.2 ft/day during the study. Flow rates were computed using equation (1). The hydraulic conductivity of the aquifer used in the computations is 84 ft/day. This value was determined from an aquifer pumping test performed at well S3B2. The effective porosity was computed as 0.16 by correlating precipitation measured at Wilmington with changes in water levels observed in well S3B1 (Appendix F). Well S3B1 was equipped with a continuous stage recorder for monitoring water levels.

The flowpath traveled by a water particle and the flow velocity of the particle determines the time that the particle will remain in the aquifer. The travel time from the ground-water divide to the ocean along flowpaths at Transect S3 averages about four years, whereas the travel time from the divide to the Intracoastal Waterway averages about 1.5 years (Table 3-8).

The shortest residence times in the shallow aquifer occur at the water table surface near the ocean and sound. Flowpaths are shortest and flow velocities are greatest in these areas. The travel time to the ocean along Transects S1 and S3 for a water particle entering the shallow aquifer at well sites S1A and S1B is typically about two months. The travel time from well site S1B to the sound along the water table at Transect S1 varies from one to four months, and the travel time from well site S3C to the sound along the water table at Transect S3 is less than one month. These travel times are representative residence times for water that enters the shallow aquifer in developed areas near the ocean and sound.

3.3.2.3 Water Levels

Ground-water levels in the shallow sand aquifer varied in response to the tide, and to recharge and discharge. Water levels rose and fell twice daily in response to tidal fluctuations. These fluctuations averaged about 0.20 ft/day at well S3B1 located in the island center, and were superimposed upon broader fluctuations that varied with recharge and discharge rates. Water levels would rise rapidly in response to recharge from precipitation and fall gradually at other times due to discharge. The observed long-term water-level recession rate due to discharge is

TABLE 3-8

GROUND-WATER FLOW VELOCITIES AND TRAVEL TIMES ALONG TRANSECTS IN SURF CITY

Site	Distance between sites (feet)	Mean water-table elevation (MSL)	Hydraulic gradient between sites (feet/foot)	Flow velocity (feet/day)	Travel time between sites (days)	Remarks
Transect S3						
B	425	2.2	1.41×10^{-3}	0.74	570	Sound side of transect
C		1.6				
B	280	2.2	3.57×10^{-4}	0.19	1500	Ocean side of transect
A		2.1				

about 0.06 ft/day. Discharge includes seepage of water to the ocean and Intracoastal Waterway, transpiration by vegetation and evaporation. Water level variations in well S3B1, which are representative of recharge and discharge conditions in the Surf City study area, are presented in Figure 3-36.

Water level measurements were made in all wells over 24-hour periods in August 1984 and February 1985 in an attempt to measure the impacts of changes in evapotranspiration on the ground-water table. Diurnal water-level fluctuations that could be attributed to evapotranspiration could not be distinguished from tidal fluctuations that were occurring in the wells.

3.3.2.4 Net Ground-Water Recharge

Net recharge to the shallow aquifer is the difference between water gains and water losses at the water-table surface. Water gains occur as infiltration from precipitation and wastewater disposal. Water losses occur as a result of evapotranspiration. Changes in water stored in the unsaturated zone overlying the shallow aquifer influence the amount of water gained by infiltration and must also be taken into account.

Net recharge along each of the transects in Surf City was computed using a monthly water budget for water gains and losses at the water-table surface (see Section 3.1.2.4). Summaries of these computations for these transects are presented in Table 3-9.

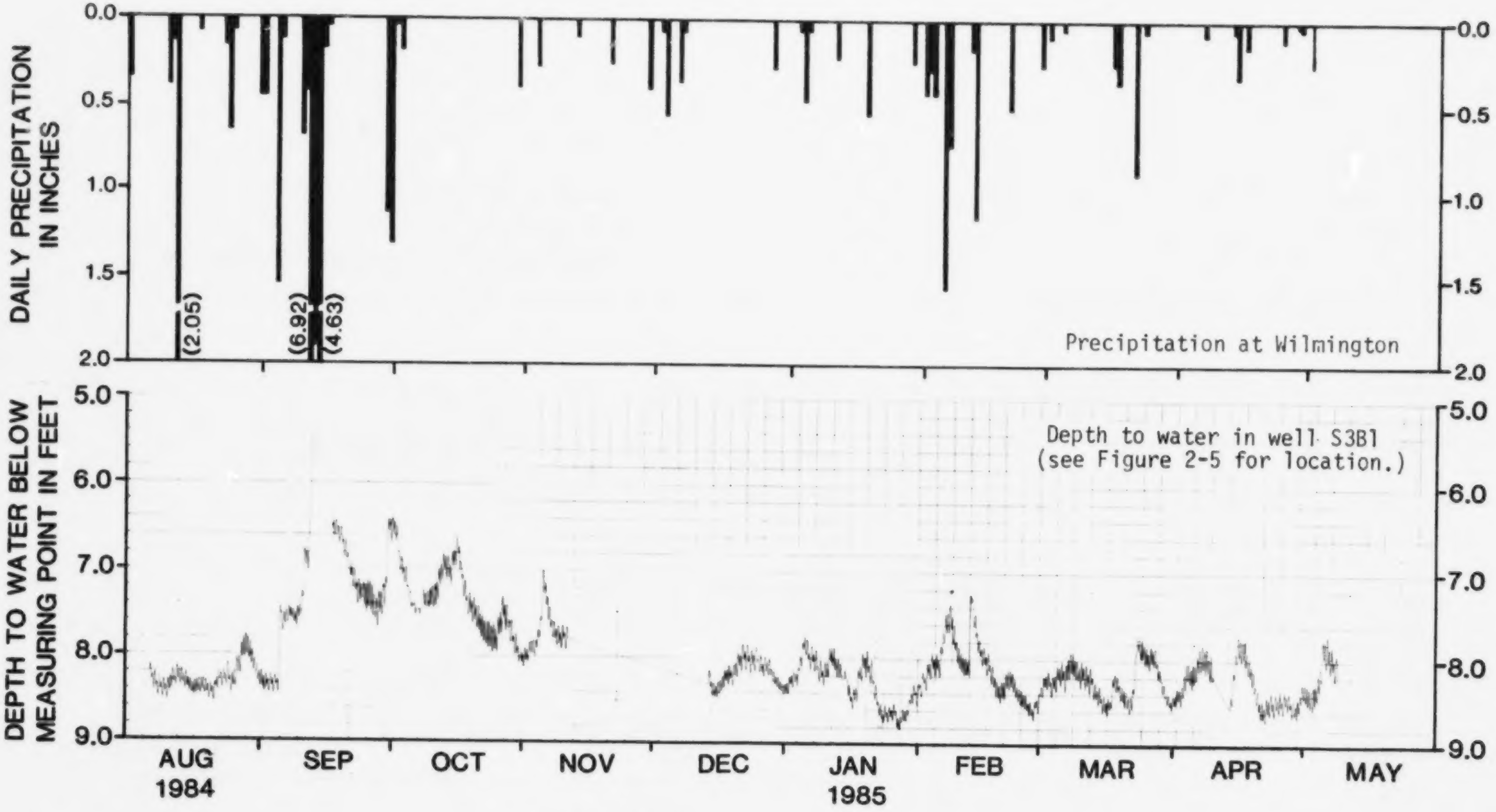
Precipitation is the major source for recharge to the shallow aquifer. Precipitation accounted for approximately 78 and 80 percent of the recharge along Transects S1 and S3, respectively. Wastewater accounted for the remainder of the recharge received along these transects.

All precipitation was assumed to infiltrate into the soil in this analysis. This assumption is reasonable as the soil is permeable and little or no runoff is observed during most rains. Also, there is no storm water collection system in Surf City to collect and convey runoff from buildings and streets. Runoff generally ponds in low areas and eventually seeps into the ground or evaporates.

Monthly precipitation for the analysis was determined from daily rainfall records collected by the National Weather Service at Wilmington, NC, located approximately 30 miles southwest of Surf City.

Wastewater disposal for the analysis was assumed to be equal to water use. Most water used by residents in Surf City is treated on-site and disposed of by infiltration of the water into the ground.

Monthly wastewater disposal was estimated from the quarterly water use records for residents along the transects. The ratio of monthly to quarterly water use, needed to distribute water use on a monthly basis, was assumed to be the same as that observed at Atlantic Beach.



EXPLANATION

(6.92) Total rainfall for the day when the total exceeds the scale

---- Dashed line represents missing water level record

Figure 3-36. Relation between ground-water levels and precipitation in the Surf City study area.

TABLE 3-9

SUMMARY OF RECHARGE COMPUTATIONS FOR TRANSECTS IN SURF CITY(1)

Transect ID	Parameter	1984							1985					Totals
		June	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	
S1	I_p	0.89	9.01	4.79	18.94	0.49	1.16	1.32	2.01	5.08	1.66	0.71	2.76	48.82
	I_w	0.65	0.63	0.78	0.21	0.51	0.45	0.23	0.66	0.28	0.53	0.39	0.68	6.00
	ΔS	-0.80	0.80	-0.80	0.80	-0.80	0	0	0.80	0	-0.18	-0.62	0.00	-0.80
	ET	1.69	6.02	5.59	3.76	1.29	1.16	1.32	0.28	0.71	1.84	1.33	2.76	27.75
	W	0.65	2.82	0.78	14.59	0.51	0.45	0.23	1.59	4.65	0.53	0.39	0.68	27.87
S3	I_p	0.89	9.01	4.79	18.94	0.49	1.16	1.32	2.01	5.08	1.66	0.71	2.76	48.82
	I_w	0.72	0.57	0.90	0.16	0.52	0.46	0.17	0.25	0.13	0.25	0.48	0.84	5.45
	ΔS	-0.80	0.80	-0.80	0.80	-0.80	0	0	0.80	0	-0.18	-0.62	0.00	-0.80
	ET	1.69	6.02	5.59	3.76	1.29	1.16	1.32	0.28	0.71	1.84	1.33	2.76	27.75
	W	0.72	2.76	0.90	14.54	0.52	0.46	0.17	1.18	4.50	0.25	0.48	0.84	27.32

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(1) All values are reported in inches.

Monthly soil moisture changes and monthly evapotranspiration used in the analyses were computed using methods outlined by the EPA (Fenn et al., 1975). These methods are described in Appendix G.

3.3.2.5 Water Quality

Ground-water samples were taken periodically for the analysis of selected parameters (Table 3-10). Water samples were generally collected in July 1984, September 1984, January 1985 and April 1985 along both Transects S1 and S3. Wells whose construction had not been completed when the July sampling was done were generally sampled in early August. The August water samples from well S3C3 were broken during shipment, so no analyses are available for this well at that time. Also, wells S3B1 and S3B5 were sampled only in January 1985.

As discussed for the previous study areas, water samples were collected in the Surf City study area with two objectives in mind. One objective was to define the relationship between saltwater and freshwater in the shallow aquifer. The second objective was to define the current impact of wastewater disposal on the quality of water in the shallow aquifer.

3.2.2.5.1 Relationship Between Freshwater and Saltwater

Measured chemical properties of the ground water used to aid in defining saltwater intrusion into the shallow aquifer included sodium concentration, chloride concentration, total dissolved solids concentration and specific conductance. Sodium and chloride are the major constituents in saltwater. Total dissolved solids measures all solids in solution in the water, including sodium and chloride. Specific conductance measures the ability of water to conduct an electrical current, and generally increases with an increase in total dissolved solids content in the water.

Elevated total dissolved solids concentrations had a strong correlation with elevated sodium and chloride concentrations in water from the shallow aquifer along both transects in Surf City, and is a good indicator of saltwater intrusion into the aquifer. The total dissolved solids content in the water was used to determine the presence of saltwater and freshwater in the shallow aquifer.

Elevated specific conductance also correlated well with increased sodium and chloride concentrations in water from the aquifer.

Variations in the total dissolved solids content of water in the shallow aquifer at Surf City are apparent. Freshwater exists at the surface of the shallow aquifer at all well sites except site S1A, where brackish water was encountered. The effects of saltwater intrusion into the aquifer increase the total dissolved solids content of the water to saline levels below the depth of the shallowest monitoring wells along Transect S1. Along Transect S3, the total dissolved solids content of the water increases to brackish levels below the depth of the shallowest monitoring wells. Definitions for fresh, brackish and saline waters are given in Section 3.1.2.5.1. The variation in total dissolved solids content along Transect S3 is shown in Figure 3-37.

TABLE 3-10

SUMMARY OF GROUND-WATER QUALITY ANALYSES FOR SURF CITY(1)

Well ID	Sampling date	Sodium	Chlo-ride	Total dis-solved solids	Ammo-nia (mg/l as N)	Nitrate plus nitrite (mg/l as N)	Alkalin-ity (mg/l as $CaCO_3$)	Hardness (mg/l as $CaCO_3$)	MBAS (mg/l)	Ortho-phosphate (mg/l as P)	Temper-ature °C	Specific conductance (µmhos/cm)	pH (s.u.)	Fecal coliform (colonies per 100/ml)
Surf City Transect S1														
S1A1	19Jul84	790	1450	3186	0.02	1.13	143	760	0.04	0.18	22	5300	7.86	<1
	16Oct84	266	493	1302	0.85	3.65	177	320	0.07	0.10	23	1550	7.72	<1
	21Jan85	5500	3381	7118	0.316	3.75	171	1000	<0.02	0.24	14	6200	7.73	2
	12Apr85	8590	1579	3602	0.73	3.66	159	758	0.03	0.13	16	3860	7.85	<1
S1A2	19Jul84	8600	17150	32970	0.10	0.16	96	5733	0.03	1.54	21	40500	7.64	<1
	16Oct84	8683	19131	23480	0.91	0.36	139	5520	<0.02	0.27	18	39000	7.45	<1
	21Jan85	7320	15226	40474	1.69	<0.05	131	5750	<0.02	0.38	-	34500	8.00	<1
	12Apr85	7510	12872	32747	5.98	0.43	125	5189	<0.02	0.09	18	25700	7.68	<1
S1A3	2Aug84	9400	18700	34048	0.02	<0.05	104	5600	<0.02	0.07	23	47243	7.50	<1
	16Oct84	9294	17700	34740	0.87	<0.05	135	5800	<0.02	0.03	19	41500	7.38	<1
	21Jan85	7460	15693	37246	1.51	<0.05	130	5900	0.03	0.10	-	37000	7.62	54
	12Apr85	7580	15842	37283	3.26	0.08	123	5320	<0.02	0.06	18	27500	7.47	<1
S1B1	19Jul84	13	31	542	0.11	0.24	135	250	0.05	0.12	25	481	7.83	<1
	16Oct84	14	26	404	<0.01	0.61	173	220	0.15	0.02	23	340	7.47	<1
	21Jan85	69	33	250	0.19	0.50	171	200	<0.02	0.13	14	315	7.97	<1
	12Apr85	850	29	246	0.12	0.42	159	197	<0.02	0.08	16	600	8.18	<1
S1B2	19Jul84	8700	16750	37096	0.45	<0.05	122	5800	0.03	0.38	22	41000	7.61	<1
	16Oct84	8467	16497	34872	0.82	<0.05	137	5200	0.04	0.13	20	39000	7.47	<1
	21Jan85	7840	14385	32344	1.55	<0.05	142	5700	<0.02	0.25	-	29000	7.66	2
	12Apr85	7440	15039	32703	3.38	<0.05	134	5207	<0.02	0.13	19	39500	7.62	<1
S1B3	2Aug84	9700	18900	36640	0.73	<0.05	143	5880	<0.02	0.19	22	51075	7.25	<1
	16Oct84	9574	16538	38788	1.04	<0.05	142	5650	0.06	0.03	22	44000	7.25	2
	21Jan85	8690	16347	35698	2.41	<0.05	146	6250	<0.02	0.50	-	40000	7.49	1
	12Apr85	8440	17000	37131	2.64	<0.05	137	5771	<0.02	0.04	19	42300	7.51	<1

TABLE 3-10
(continued)
SUMMARY OF GROUND-WATER QUALITY ANALYSES FOR SURF CITY

Well ID	Sampling date	Sodium	Chloride	Total dissolved solids	Ammonia (mg/l as N)	Nitrate plus nitrite (mg/l as N)	Alkalinity (mg/l as $CaCO_3$)	Hardness (mg/l as $CaCO_3$)	MBAS (mg/l)	Orthophosphate (mg/l as P)	Temperature °C	Specific conductance (µmhos/cm)	pH (s.u.)	Fecal coliform (colonies per 100/ml)
Surf City (cont'd) Transect S3														
S3A1	19Jul84	16	36	528	0.19	0.96	135	258	<0.02	0.06	22	403	7.31	2
	16Oct84	49	103	698	<0.01	<0.05	208	420	<0.02	0.03	21	970	7.27	<1
	21Jan85	121	64	602	0.09	4.15	193	445	<0.02	4.20	14	610	7.67	<1
	12Apr85	850	196	789	0.27	2.78	146	357	<0.02	0.04	16	1050	7.48	<1
S3A2	19Jul84	3080	6500	12874	0.16	<0.05	178	2500	<0.02	1.05	22	15000	7.48	<1
	16Oct84	2601	4666	9924	0.37	<0.05	234	1900	0.03	0.62	18	25800	7.17	<1
	21Jan85	2210	4203	9700	0.84	<0.05	228	2050	<0.02	0.05	-	17400	7.65	<1
	12Apr85	2280	3829	8643	0.67	<0.05	212	1466	<0.02	0.38	18	12100	7.67	<1
S3A3	2Aug84	7400	15300	30108	0.05	<0.05	148	5500	<0.02	1.84	22	40755	7.08	>4600
	16Oct84	7375	13894	34924	0.97	<0.05	250	4840	<0.02	0.31	18	34000	7.10	<1
	21Jan85	5980	11956	27222	3.17	<0.05	175	4875	0.08	0.19	-	29900	7.38	<1
	12Apr85	5950	12890	28795	2.25	1.60	146	4568	<0.02	0.37	18	32800	7.33	1
S3B1	21Jan85	72	14	206	0.07	<0.05	154	158	<0.02	0.04	19	345	8.18	<1
S3B2	19Jul84	710	1400	3312	0.12	<0.05	204	1040	<0.02	0.32	23	3850	7.55	<1
	16Oct84	830	1669	4020	0.17	<0.05	225	860	<0.02	0.14	19	6800	7.34	<1
	21Jan85	970	1495	3444	0.57	<0.05	230	900	<0.02	0.20	-	8500	7.57	2
	12Apr85	1200	1171	3130	1.25	1.44	239	752	0.02	0.18	18	4550	7.59	<1
S3B3	19Jul84	6100	11750	22252	0.39	<0.05	165	3300	<0.02	0.32	23	26500	7.33	<1
	16Oct84	6229	10980	24436	0.17	<0.05	340	3940	<0.02	0.84	19	28700	7.15	<1
	21Jan85	5870	9621	20802	1.73	<0.05	203	4550	<0.02	1.43	-	25900	7.47	<1
	12Apr85	5750	10555	22605	2.75	0.72	182	3760	0.04	0.36	18	25800	7.44	<1
S3B4	19Jul84	11000	21300	39590	0.61	<0.05	256	5900	<0.02	0.34	23	43000	6.93	<1
	16Oct84	10395	20168	52648	<0.01	<0.05	347	7020	<0.02	0.16	19	47700	6.93	2
	21Jan85	15810	16207	37218	3.14	<0.05	324	6900	<0.02	0.08	-	41000	7.19	<1
	12Apr85	8590	18869	40798	7.60	0.77	310	6519	0.03	0.22	18	35500	7.35	<1
S3B5	21Jan85	160	78	438	0.34	<0.05	218	250	<0.02	0.07	18	4700	7.94	<1
S3C1	19Jul84	8	10	682	0.56	0.45	200	260	0.04	0.14	22	435	7.35	<1
	16Oct84	9	15	268	0.16	<0.05	198	270	<0.02	0.04	19	480	7.45	<1
	21Jan85	82	93	226	0.42	<0.05	166	250	<0.02	0.08	13	305	7.94	<1
	12Apr85	560	63	643	0.45	<0.05	205	237	0.02	0.23	15	590	7.89	<1
S3C2	19Jul84	1830	3650	7688	0.47	0.07	209	2000	0.05	0.28	22	9800	7.64	<1
	16Oct84	2300	3826	8580	<0.01	<0.05	225	1470	<0.02	0.23	19	14000	7.52	<1
	21Jan85	2190	3363	7586	1.23	<0.05	228	1400	<0.02	0.13	13	10000	7.67	<1
	12Apr85	1350	3940	7992	2.93	0.62	216	1407	<0.02	0.32	18	10100	7.76	<1
S3C3	16Oct84	9487	16788	37122	0.16	<0.05	413	5980	<0.02	1.41	19	40500	7.02	<1
	21Jan85	8170	17655	35654	3.46	<0.05	448	6425	<0.02	0.15	-	35200	7.00	<1
	12Apr85	8390	19408	42633	4.57	0.06	430	6278	<0.02	0.24	17	43500	7.05	<1

[1] All analyses are in milligrams per liter (mg/l) unless otherwise noted.

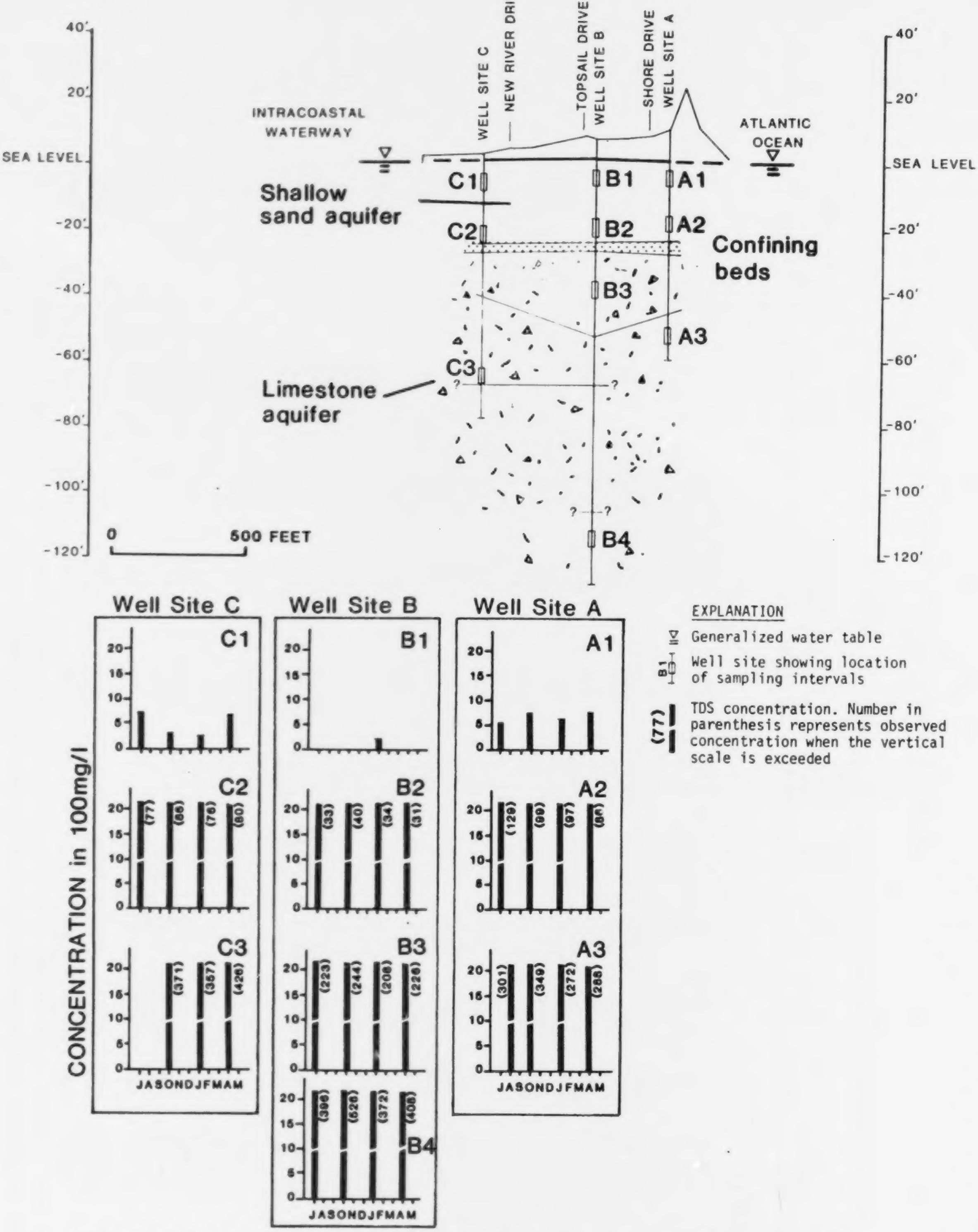


Figure 3-37. Variation in total dissolved solids concentration along Transect S3.

3.3.2.5.2 Effects of Wastewater Disposal

Measured chemical properties of the ground water used to aid in defining the effects of wastewater disposal to the shallow aquifer included nitrate plus nitrite concentration (nitrate/nitrite), ammonia concentration, orthophosphate concentration, methylene blue active substances (MBAS) concentration, and fecal coliform concentration. Nitrate, nitrite, ammonia and orthophosphate are common nutrients present in wastewater. MBAS are substances used in detergents and do not occur naturally in the environment. Fecal coliform are a group of bacteria which come from the intestines of mammals and may be found in wastewater and sometimes in storm water runoff.

Nitrate/nitrite and ammonia, reported in mg/l as nitrogen (N), were detected in ground water along both transects in Surf City (Table 3-10). Variations in nitrate/nitrite and ammonia concentrations along Transect S3 are shown in Figures 3-38 and 3-39, respectively. Although data is sporadic, a trend toward decreasing nitrate/nitrite concentrations with depth is indicated for Transect S3. The same trend is more apparent upon examination of the data for Transect S1. The highest nitrate/nitrite concentrations of the study were detected from Surf City wells, with concentrations generally greater than 3 mg/l at well S1A1 and concentrations as high as 4.15 mg/l at well S3A1. Ammonia concentrations showed a definite trend to increase with depth along both Surf City transects.

Nitrate, nitrite and ammonia are contaminants which are commonly found in ground water. The presence of these constituents in the shallow ground water could, therefore, be indicative of the impact of wastewater disposal. The drinking water standard for nitrates is 10 mg/l as nitrogen (N). There are no drinking water standards for ammonia.

Orthophosphates, reported in mg/l as phosphorus (P), were also detected in ground water along both transects. Variations in orthophosphate concentrations along Transect S3 are shown in Figure 3-40. Orthophosphate concentrations along Transect S3 appear to increase with depth, with the exceptions of well S3B4, which shows a definite decrease, and the January reading from well S3A1, which is among the highest of the study.

The presence of phosphorous compounds in the ground water is typically a result of wastewater disposal. The usual sources for phosphorous are organic waste products and phosphate detergent residues. The highest observed level of orthophosphate was 4.20 mg/l. There are no drinking water standards for orthophosphates.

Only minor concentrations of MBAS were detected in ground-water samples from monitoring wells at Surf City. The highest MBAS level detected was 0.15 mg/l at well S1B1. The recommended secondary drinking water standard for MBAS is 0.50 mg/l. The source of MBAS in wastewater is synthetic foaming agents present in modern detergents. Variations in MBAS concentration detected along Transect S3 are shown in Figure 3-41.

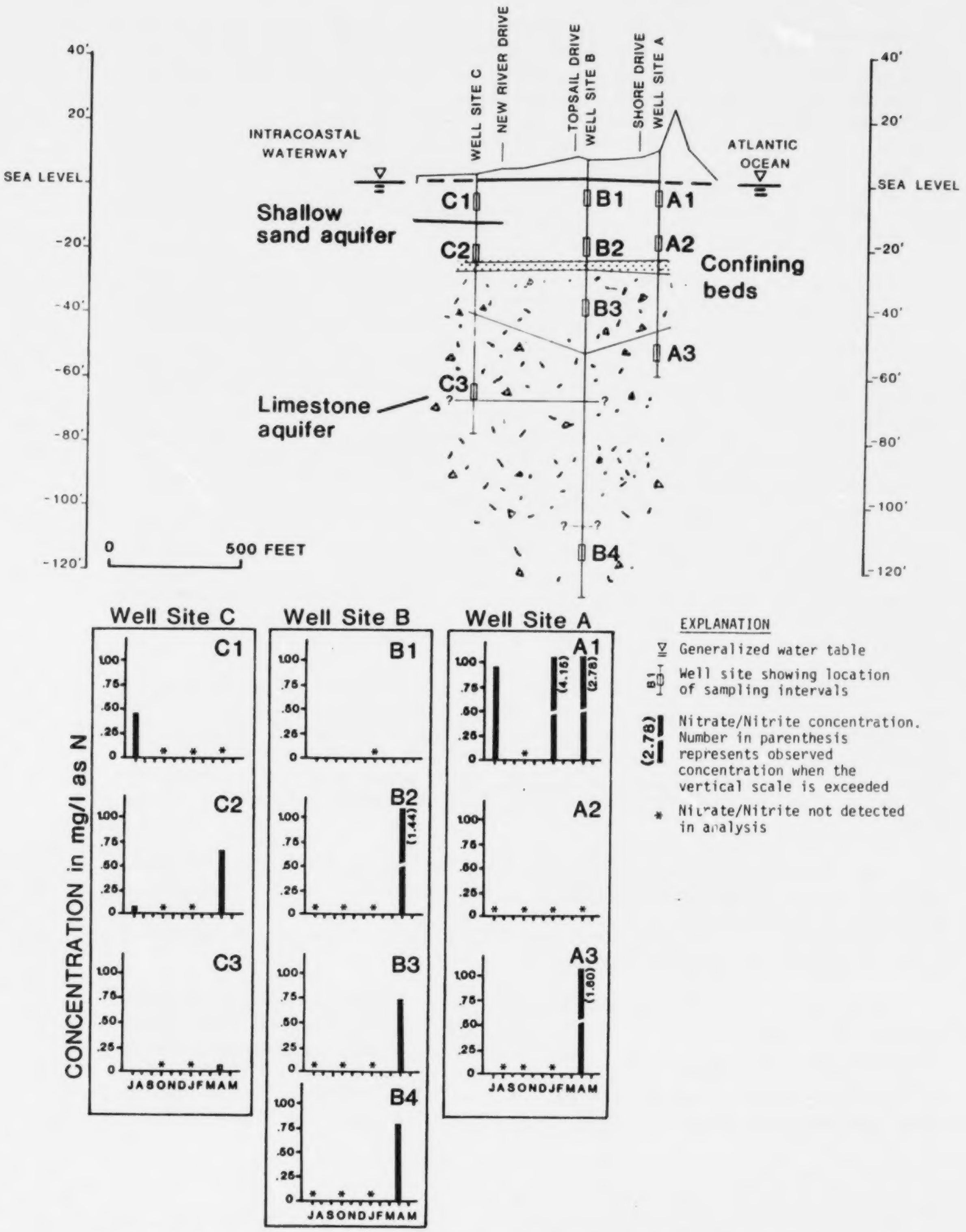


Figure 3-38. Variation in nitrate plus nitrite concentration along Transect S3.

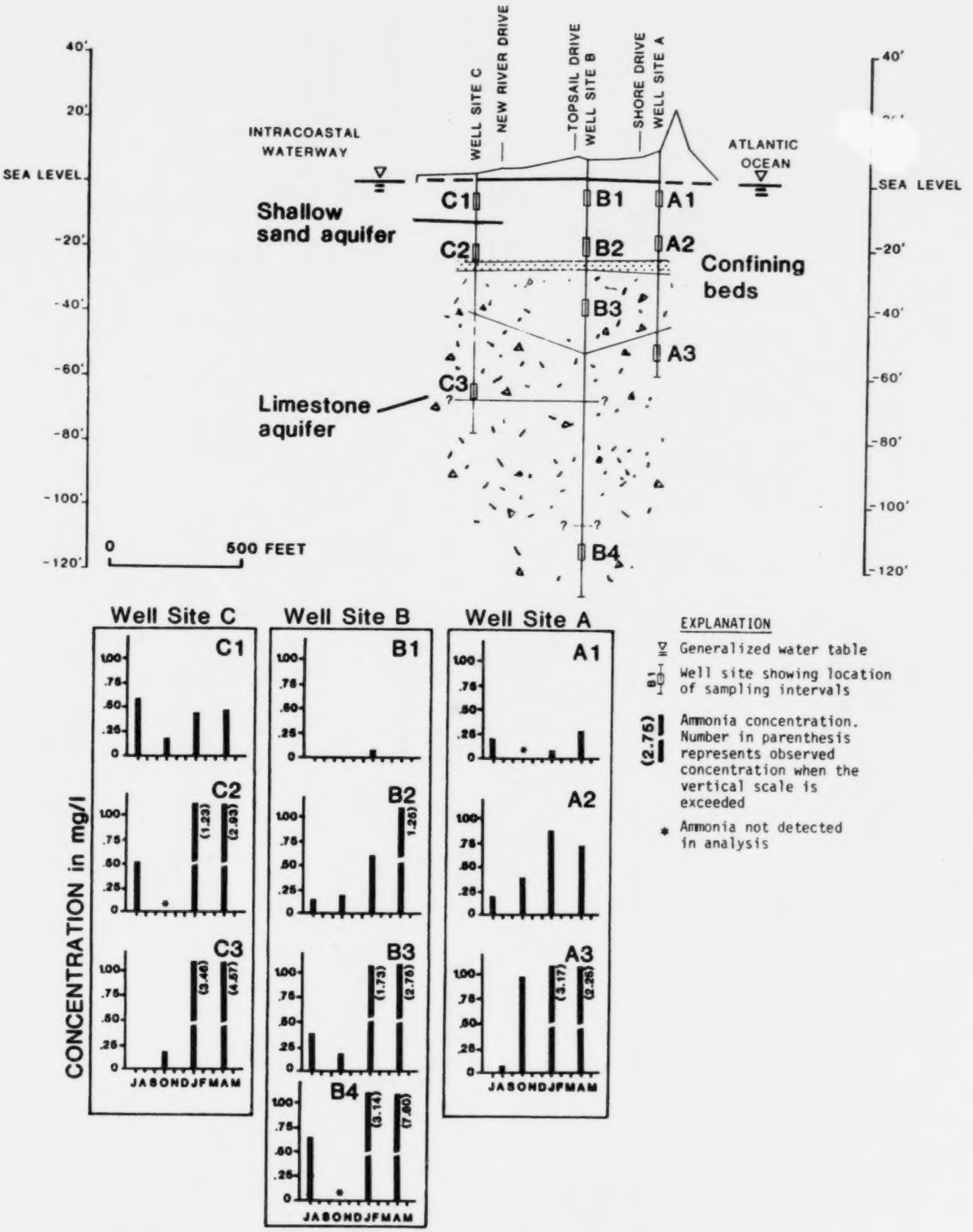


Figure 3-39. Variation in ammonia concentration along Transect S3.

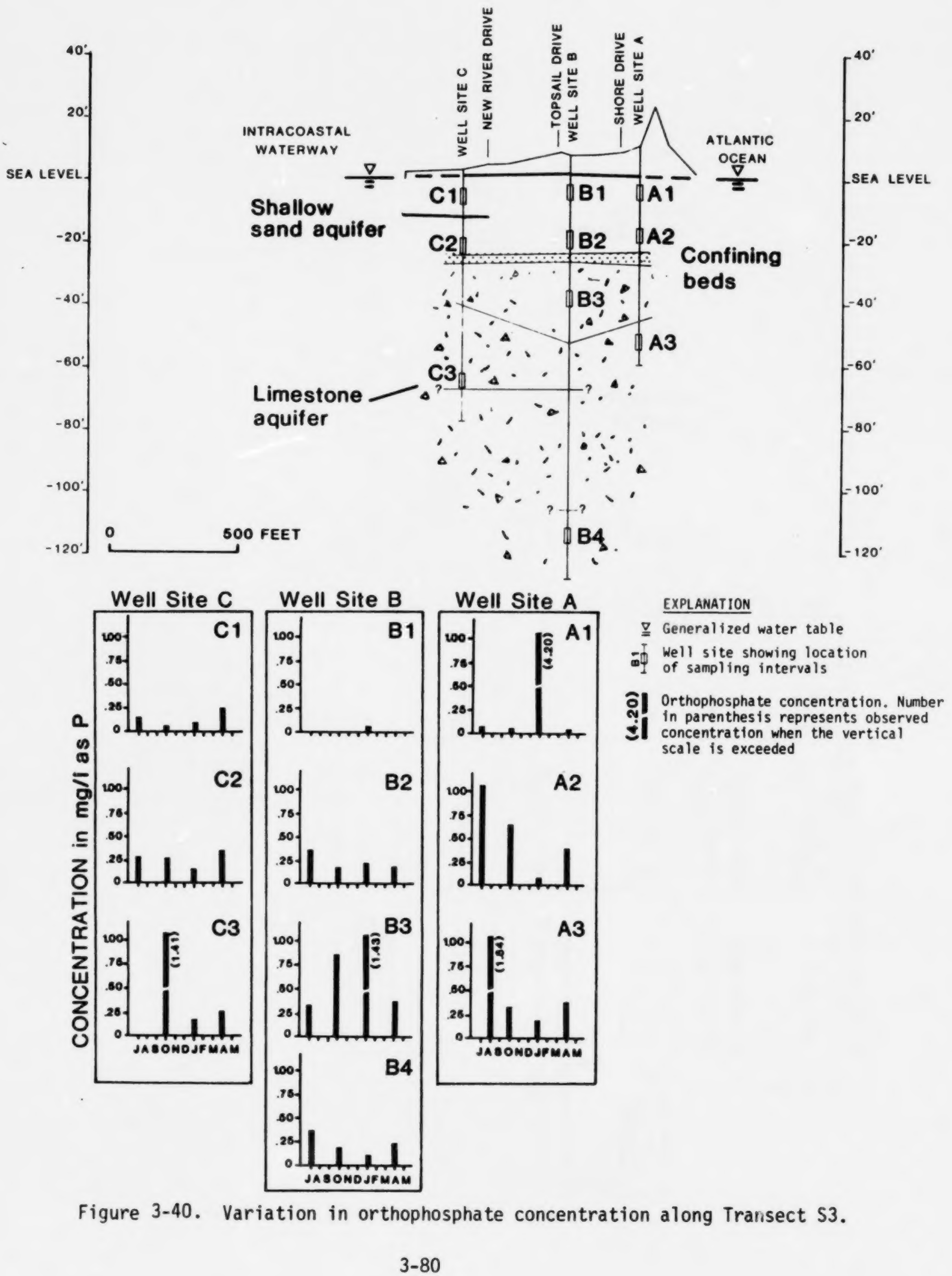


Figure 3-40. Variation in orthophosphate concentration along Transect S3.

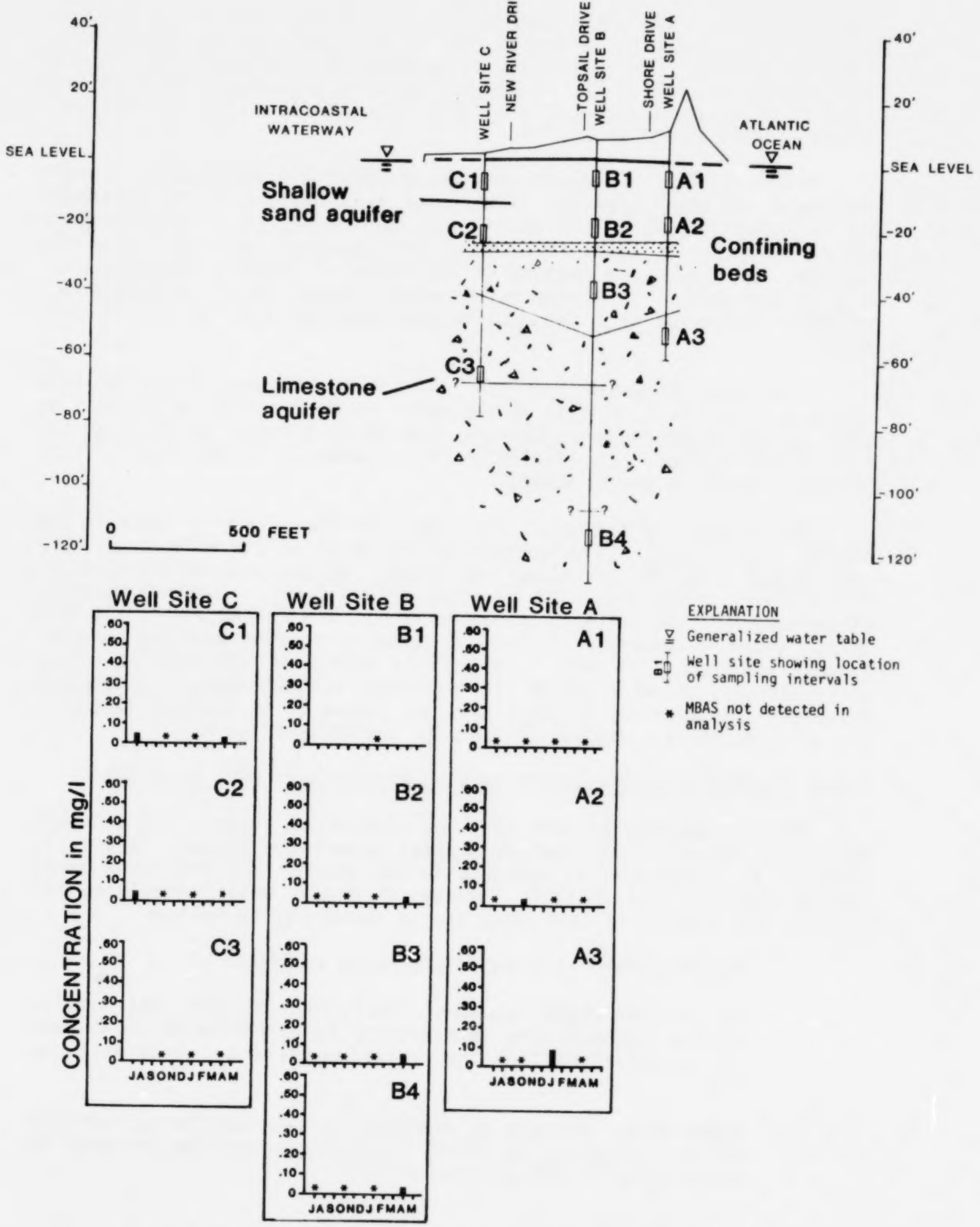


Figure 3-41. Variation in MBAS concentration along Transect S3.

Fecal coliform were found in 10 of the 61 ground-water samples collected in Surf City. The fecal coliform count in eight of the samples, however, was either one or two col/100 ml. One of the two high concentrations occurred in August 1984 in well S3A3 and was greater than 4,600 col/100 ml. The other high value occurred in January 1985 in well S1A3 and was 54 col/100 ml. The significance of high fecal coliform concentrations in these deep wells without intermediate values in shallower adjacent wells is not known.

Alkalinity and hardness of the ground water were measured as overall indicators of water quality. Alkalinity is a measure of the carbonate and bicarbonate ions in the water, with maximum levels of approximately 400 mg/l as calcium carbonate ($CaCO_3$) considered to represent no health problem. Hardness is a measure of the amount of calcium, magnesium and iron in the water. A strong relationship between these parameters and saltwater intrusion into the aquifer was observed from the data (Table 3-10).

Alkalinity in water from the shallow aquifer was fairly uniform (Table 3-10). The alkalinity of the water ranged from 135 to 200 mg/l as $CACO_3$ at the water-table surface and from 96 to 218 mg/l as $CaCO_3$ at the base of the aquifer. The alkalinity of the water is in the range of that generally found in ground waters.

The hardness of the water increased significantly with depth in the aquifer (Table 3-10). The hardness of the water at the water-table surface ranged from 158 to 760 mg/l as $CaCO_3$. At the base of the aquifer, the hardness ranged from 2000 to 5800 mg/l as $CaCO_3$. The high hardness at the aquifer base reflects saltwater intrusion into the aquifer in that area. Water is generally considered to be hard water when the hardness exceeds 150 mg/l, and very hard when in excess of 300 mg/l as $CaCO_3$. Since hardness in water can be easily removed with treatment, and because hardness concentrations in water have not proven to be health-related, no criterion exists for raw waters used for public water supply.

3.3.3 Summary of Hydrogeologic Setting for the Surf City Study Area

The hydrogeology at Surf City was studied to identify the movement of ground water in the shallow aquifer underlying Topsail Island, to identify the components of recharge to the aquifer and their magnitude, and to identify the existing quality of ground water underlying the island. The results of this study can be summarized as follows:

- Topsail Island is underlain by three aquifers.
- The shallow sand aquifer, consisting of sand and shells, extends downward from land surface to depths of 30 to 40 feet and is separated from the deeper aquifers by sandy silt and clay.
- Ground-water movement in the shallow sand aquifer is variable and is influenced by tidal fluctuations and the presence of saline water in the aquifer.

- Precipitation accounted for about 80 percent of the recharge to the shallow sand aquifer and wastewater accounted for the remainder.

- Brackish to saline water occurs near the base of the shallow sand aquifer and is also present throughout the aquifer in the vicinity of well site S1A.

- Disposal of wastewater into the shallow aquifer has had a minor impact on ground-water quality.

4.0 PROBABLE HYDROLOGIC IMPACTS ASSOCIATED WITH DEVELOPMENT ACTIVITIES

The probable impacts on ground-water levels and water quality of continued development on the barrier islands were investigated. The data collected during this study formed the basis for the investigation.

4.1 Ground-Water Levels

A simple analytical model for computing changes in ground-water levels that might result from increased wastewater disposal to the aquifer system underlying the islands was identified and tested. This model was based on the physical characteristics of the islands and underlying aquifer system.

4.1.1 Identification of Predictive Water-Level Model

The aquifer system underlying each of the barrier islands studied consisted of an upper unconfined or semiconfined aquifer that overlies deeper confined aquifers. The upper aquifer is composed of sands and shells and is separated from the lower aquifers by confining beds that are composed of silt and clay. Water movement to the deeper aquifers is restricted due to the presence of the confining beds. The confining beds occur at depths varying from as little as 25 feet at Atlantic Beach to as much as 100 feet at Kill Devil Hills.

Ground-water movement in the upper, or shallow, aquifers is generally away from the central part of the islands toward discharge points in the ocean and sound. Flowpaths along cross-sections perpendicular to the islands are similar in this case.

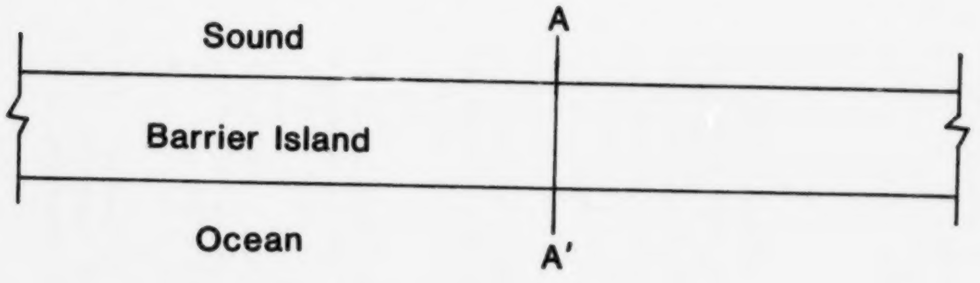
The shallow aquifer in each study area can be represented approximately as an aquifer of infinite length and narrow width that is composed of permeable sands and shells. The upper boundary of this model aquifer consists of a water table that is free to move vertically. Its lower boundary consists of relatively impermeable confining beds. The model aquifer is in hydraulic communication with constant head boundaries along each side throughout its length. A schematic representation of this model aquifer is presented in Figure 4-1.

Water movement through the model aquifer occurs laterally, with movement being from the center of the aquifer toward the constant head boundaries. Water discharges from the aquifer at the interface with these boundaries.

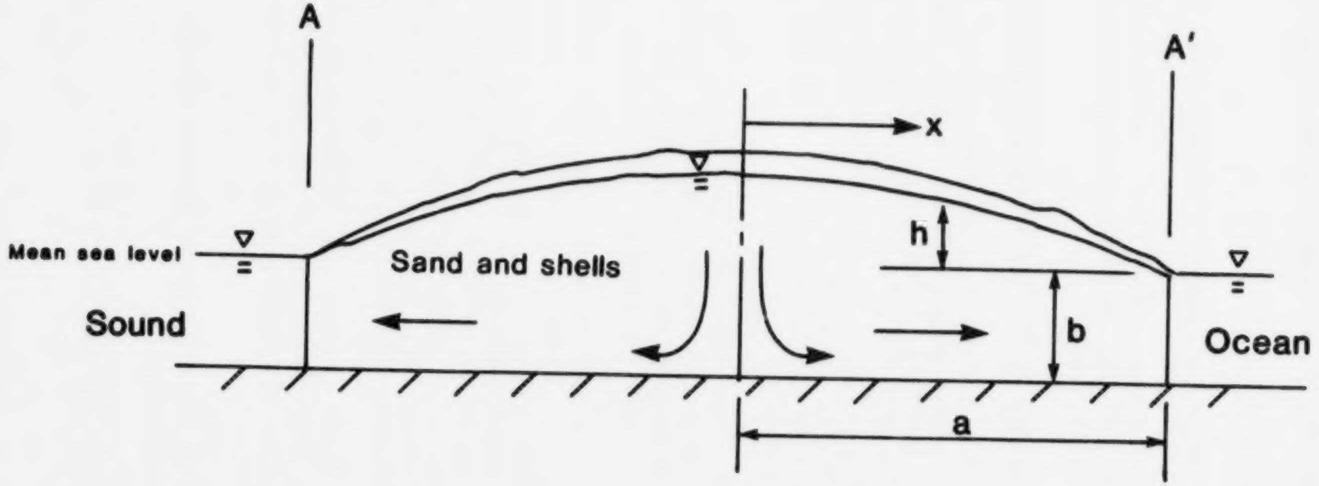
The equation for describing the average position of the water table in the model aquifer is:

$$H^2 = \frac{W(a^2 - x^2)}{K} + b^2 \tag{3}$$

where: H = thickness of the water table aquifer, in feet;


Sound
A
Barrier Island
Ocean
A'

a. Plan view of model aquifer.


A
A'
x
Mean sea level
Sand and shells
h
b
Sound
Ocean
a

b. Cross-section through model aquifer.

EXPLANATION

▽ Generalized water table

← Generalized ground-water flowpath

Figure 4-1. Simplified model for the shallow aquifer.

W = net recharge to the water table, in feet per day;

K = hydraulic conductivity of the aquifer, in feet per day;

a = half-width of the island, in feet;

b = depth below mean sea level to the top of the confining beds, in feet; and

x = distance from the center of the island to the point at which the water table elevation is required, in feet.

This equation is derived from the more general equation for finding the elevation of the water table at any point between two constant head boundaries of differing elevations (Fetter, 1980).

The water-table elevation is related to the aquifer thickness (H) and depth below land surface to the confining beds (b) by the equation:

$$h = H - b \tag{4}$$

where: h = height above mean sea level to the water-table surface, in feet.

The variables a, x, b and h for the model aquifer are depicted in Figure 4-1.

Equation (3) is applicable to shallow aquifers on the barrier islands when flow in the aquifer is predominantly horizontal, there is no intrusion of saline water into the aquifer under the island and tidal fluctuations have little or no effect on water levels. These conditions are met reasonably well in the shallow aquifers in Kill Devil Hills and Pine Knoll Shores and are probably met in the shallow aquifer in Atlantic Beach.

Equation (3) cannot be applied to the shallow aquifer in Surf City. Ground water of variable density underlies freshwater at very shallow depths in the aquifer. Also, tidal fluctuations have a strong effect on water levels in this study area. These conditions violate the assumptions used to derive the model equation.

4.1.2 Model Calibration

Measured average water-table elevations and those computed for each transect using equation (3) did not agree using parametric values determined as a part of this study. For all transects except P2 in Pine Knoll Shores, the computed elevations were substantially lower than those which were measured. The computed elevations along Transect P2 were higher than measured elevations.

An analysis of the variables in equation (3) indicated that the hydraulic conductivities that should be used in this equation are generally lower than those determined by aquifer pumping tests. Apparent hydraulic conductivities for each transect therefore were computed by solving the equation for hydraulic conductivities using the measured water-table elevation data. The ratio of hydraulic conductivity from aquifer pumping tests to apparent hydraulic conductivities for the transects varied from 0.7 to 5.0 (Table 4-1).

The differences between measured hydraulic conductivities and computed apparent hydraulic conductivities probably reflects in large part differences between horizontal and vertical values of hydraulic conductivity, or anisotropy, in the shallow aquifers. The aquifer pumping tests measured horizontal hydraulic conductivity. The computed apparent hydraulic conductivites include the integrated effects of variations in horizontal and vertical hydraulic conductivities. Layering of the sands, shells and silty sands noted in the shallow aquifers would be responsible for this anisotropy. Ratios of horizontal to vertical hydraulic conductivities between 2 and 20 are commonly found in relatively clean sands (Fetter, 1980).

Changes required in the other independent variables in equation (3) to match water-table elevations at the center of the island may not be justified. The net recharge required to reproduce the observed water-table elevations at the island center was generally twice that which reasonably could be expected on the barrier islands. The measured aquifer thickness along the transects would generally need to be reduced by 50 percent or more and the measured island half-width would generally need to be increased by a factor of 1.5 to 2 in order to produce acceptable results.

Average water-table elevations computed along transects for the study period using equation (3) with the calibrated apparent hydraulic conductivities were in fair agreement with observed elevations in the center one-half of the transects (Table 4-2). The recharge values needed for these computations were taken from the water balance analyses for the transects. The aquifer thickness below sea level and island half-width needed for the computations were determined from the hydrogeologic cross-sections.

Observed water-table elevations are higher in areas near the ocean and sound than those computed using equation (3). One reason for this discrepancy is that no allotment was made for the subsea outflow face that must exist for freshwater to discharge into either the ocean or the sound. Anisotropy in the aquifer deposits, higher wastewater loadings in the areas near the ocean and sound, and average elevations of the ocean and sound greater than mean sea level would be other reasons for this discrepancy.

An equation that accounts for the presence of the subsea outflow face can be used to compute water-table elevations near the ocean and sound (Fetter, 1980). This equation is

$$h = \left(\frac{qx'}{20K} \right)^{1/2} \qquad (5)$$

TABLE 4-1

COMPARISON BETWEEN MEASURED AND APPARENT HYDRAULIC CONDUCTIVITIES

Transect ID	Measured hydraulic conductivity (K,ft/day)	Apparent hydraulic conductivity (K_A,ft/day)	$\frac{K}{K_A}$
K1	73	22.3	3.3
K2	73	27.6	2.6
K3	73	36.3	2.0
A1	63	12.5	5.0
A2	63	34.5	1.8
P1	63	24.0	2.6
P2	63	90.4	0.7

TABLE 4-2

COMPUTED AND OBSERVED WATER-TABLE ELEVATIONS ALONG TRANSECTS

Transect ID	Site	Island half-width (feet)	Net recharge (ft/day)(2)	Aquifer thickness below sea level (feet)	Distance from island center (feet)	Computed water-table(1) elevation (MSL)	Mean water-table elevation (MSL)	Obeserved range in water-table elevation (MSL)
Kill Devil Hills								
K1	C	2060	.00416	55	0	6.2	6.2	5.6-7.3
	B				625	5.7	6.0	5.5-7.1
	D				800	5.4	5.1	4.5-6.3
	A				1625	2.4 (2.9)	4.2	3.0-7.1
	E				1875	1.1 (1.9)	3.1	2.2-3.4
K2	C	2460	.00431	75	250	6.0	6.0	5.5-7.2
	D				975	5.1	6.9	6.1-8.2
	B				1200	4.7	5.0	4.3-5.8
	A				2125	1.6 (2.5)	3.7	2.4-5.8
	E				2450	0 (0.4)	2.0	1.6-2.4
K3	D	3900	.00403	75	500	10.4	10.4	10.1-11.6
	C				575	10.4	9.6	9.1-10.8
	E				1575	8.9	8.4	7.2-9.6
	B				1750	8.5	6.8	6.3-7.9
	F				2450	6.5	6.2	5.9-6.8
	A				3425	2.5 (3.2)	3.7	2.9-5.3
	G				3550	1.9 (2.8)	2.0	1.8-2.1
Atlantic Beach								
A1	B	655	.00873	35	150	3.8	4.2	3.3-6.7
	C				225	3.6	3.9	3.0-6.0
	A				525	1.5 (1.7)	3.2	2.7-4.7
	D				525	1.5 (1.7)	2.4	1.6-3.6
A2	B	900	.00863	22	125	4.1	4.2	3.4-6.5
	C				505	3.0	2.6	1.9-3.4
	A				690	1.8	3.2	2.6-4.7
Pine Knoll Shores								
P1	C	1465	.00637	50	62	5.3	5.4	4.3-7.4
	D				490	4.8	4.8	3.8-7.0
	B				650	4.4	5.1	4.2-5.9
	E				1090	2.5 (2.7)	3.6	3.1-5.3
	A				1250	1.5 (2.0)	4.3	3.5-5.3
P2	C	1960	.00688	40	335	3.4	3.5	2.7-4.8
	D				850	2.9	2.6	2.3-3.7
	B				1275	2.0	4.0	3.4-5.5
	E				1810	0.5 (1.1)	2.5	1.8-3.3
	A				1860	0.4 (0.9)	3.2	2.3-4.2

---

(1) Number in parenthesis is the water table elevation computed using equation (5).

(2) Net recharge is based on June 1984 to February 1985 data for Kill Devil Hills, June 1984 to April 1985 data for Atlantic Beach and June 1984 to March 1985 data for Pine Knoll Shores.

where: x' = distance inland from the shoreline, in feet;

q = discharge per unit length of shoreline, in cubic feet per day per foot; and

K = apparent hydraulic conductivity, in feet per day.

The discharge per unit length of shoreline is related to net recharge by the equation

$$q = Wa \tag{6}$$

where W and a have been defined earlier. Equation (5) is valid to a distance inland from the shoreline of about $0.25a$.

The water-table elevations near the ocean and sound computed using equation (5) are in closer agreement to observed results than those computed using equation (3)(Table 4-2). The observed water-table elevations, however, are still generally higher than the computed elevations. The remaining discrepancy between measured and computed water-table elevations probably results from one or more of the additional reasons stated earlier.

4.1.3 Model Use for Estimating Changes in Ground-Water Levels

The impacts of wastewater disposal during the study period on water levels along transects were investigated using equation (3). Computed water-table elevations resulting from precipitation were compared with computed water-table elevations resulting from precipitation plus recharge by wastewater disposal (Table 4-3).

The increase in water-table elevations resulting from wastewater disposal during the study period was greater at Atlantic Beach than at either Kill Devil Hills or Pine Knoll Shores. Intuitively, this is expected, as the largest wastewater loading to the aquifer system is occurring at Atlantic Beach. The water-table elevation is approximately one foot higher at the center of Bogue Banks in Atlantic Beach than that which would occur if there was no wastewater disposal on the island. The water-table elevations at Kill Devil Hills and Pine Knoll Shores are about 0.6 feet and 0.1 to 0.4 feet higher, respectively, than those that would occur without the addition of wastewater.

The impact of equal volumes of wastewater disposal on changes in average water levels, however, was greatest at Kill Devil Hills. That is, rises in water levels per unit volume of wastewater disposal at transects in Kill Devil Hills were greater than those which occurred at transects in the other study areas. A closer examination of equation (3) indicates that water-table elevations are relatively sensitive to island width and depth to confining beds. The greater the combination of island width and depth to confining beds (within the range of widths and depths investigated in this study), the greater the impact of incremental values of recharge on changes in water levels.

TABLE 4-3

COMPUTED AVERAGE WATER-TABLE ELEVATIONS AT CENTER OF TRANSECTS WITH AND WITHOUT WASTEWATER DISPOSAL

Transect ID	Recharge by rainfall (ft/day)	Water-table elevation resulting from rainfall disposal (MSL)	Recharge by rainfall plus wastewater disposal (ft/day)	Water-table elevation resulting from rainfall plus wastewater disposal (MSL)
Kill Devil Hills				
K1	.00377	5.7	.00416	6.3
K2	.00377	5.3	.00431	6.0
K3	.00377	9.9	.00403	10.5
Atlantic Beach				
A1	.00625	2.9	.00873	4.0
A2	.00625	3.1	.00863	4.2
Pine Knoll Shores				
P1	.00625	5.3	.00637	5.4
P2	.00625	3.1	.00688	3.5
Surf City				
S1	.00600	1.6	.00735	2.0
S3	.00600	1.7	.00713	2.0

Wastewater disposal at Surf City may be causing ground-water levels there to be 0.3 to 0.4 feet higher than those that would occur naturally (Table 4-2). This estimate is based on using equation (3), which, although not strictly applicable to hydrologic conditions at Surf City, does provide a means for obtaining rough estimates.

The data used for the above computations are essentially the same as that data used earlier for computing average water-table elevations along transects. However, for computing water-table elevations resulting from precipitation, wastewater recharge along each transect was subtracted from total recharge along the transect.

Equation (3) estimates the average impact of wastewater disposal on water-table elevations and assumes that steady-state conditions prevail in the aquifer. These limitations restrict the usefulness of this equation. The impact of changes in wastewater disposal volumes over short time periods, such as one season of the year, cannot accurately be taken into account.

The utility of equation (3) to planning for wastewater management lies in its ability to estimate the cumulative impacts of development on ground-water levels. The equation could be used to compute the maximum probable impact that various incremental increases in wastewater disposal would have on observed average water-table elevations.

4.1.4 Model Use for Planning Purposes

Suppose that long-range development plans in an area call for a maximum population growth such that the increased average water use across the island will amount to an additional wastewater disposal rate to the shallow aquifer of 10.0 inches per year. The problem is to determine the probable impact of this added wastewater disposal on water levels in the shallow aquifer.

The first step in determining the probable impact on water levels is to determine the depth below mean sea level of the confining beds at the island mid-point and within the area of interest. A boring could be drilled for this purpose. In our case, let us assume the depth below land surface to the confining beds is found to be 60.0 feet and that the land surface elevation is 10.0 feet. The depth below mean sea level to the confining beds would then be 50.0 feet.

The next step is to determine the elevation of the water table at the island mid-point. To accomplish this, the boring drilled to determine the depth to confining beds can be backfilled to a point about 10 feet below the water table and completed as a shallow monitoring well. The depth to water in this well, measured from a reference point on the well that has been surveyed and has a known elevation, can be used to determine the water-table elevation in the area. Let us assume that the water-table elevation determined in this manner is 4.00 feet.

The third step is to determine the half-width of the island. This information can be taken from any acceptable base map for the area. For our example, let us assume that the island half-width is 1,500 feet.

The fourth step is to estimate current yearly net recharge to the shallow aquifer in the proposed development area. Current yearly net recharge includes recharge from precipitation and wastewater disposal. A good estimate for long-term yearly recharge from precipitation is 20.0 inches per year based on work done by Wilder (1978) in northeast North Carolina and work done by Winner on the barrier islands. Current wastewater disposal can be assumed to be equal to water use and can be determined from water use records. Yearly net recharge will be 21.0 inches, assuming for our example that wastewater disposal is equivalent to one inch.

The information needed to determine the impact on water levels of the added wastewater disposal is now available. The apparent hydraulic conductivity is computed from equation (3) and found to be 25.9 ft/day. The estimated current water-table elevations across the island are now computed using equation (3), the apparent hydraulic conductivity and current yearly net recharge. The computational process is then repeated after adding the additional wastewater disposal to the yearly net recharge. The difference between water-table elevations computed with and without the added wastewater disposal is the impact on water levels for the proposed development. A summary of the computations is presented in Table 4-4. A flow diagram showing the computational process is presented in Figure 4-2.

4.1.5 Water-Table Fluctuations Due to Short-Term Precipitation Events

Caution must be exercised when using equation (3) to assess the impacts of wastewater disposal. In our example, the estimated increase in water levels due to the increased wastewater disposal will be approximately two feet at the center of the island. The water table was six feet below land surface at this point when the monitoring well was drilled, suggesting that a two-foot rise would not cause the ground-water table to surface. However, water-table fluctuations of two or three feet caused by precipitation were observed on the barrier islands during the course of this study. These fluctuations need to be considered in any detailed analysis involving assessment of the probability of ground-water levels surfacing due to increased water-table elevations caused by wastewater disposal.

The probability for a given rise in the water table is directly related to the probability of various rainfall events. Estimated short-term rises in the ground-water table for 24-hour rainfall events with recurrence intervals of 5, 10, 25, 50 and 100 years are tabulated in Table 4-5. The water-table rise was computed by dividing rainfall by aquifer porosity and is only applicable to that point where the water table surfaces.

TABLE 4-4

IMPACTS ON WATER LEVELS OF PROPOSED DEVELOPMENT FOR HYPOTHETICAL CASE

Distance from island center (feet)	Computed existing water-table thickness (feet)	Computed water-table thickness after development (feet)	Increase in water-table level (feet)
0	54.0	55.8	1.8
300	53.8	55.6	1.8
600	53.4	54.9	1.5
900	52.6	53.8	1.2
1,200	51.5	52.2	0.7

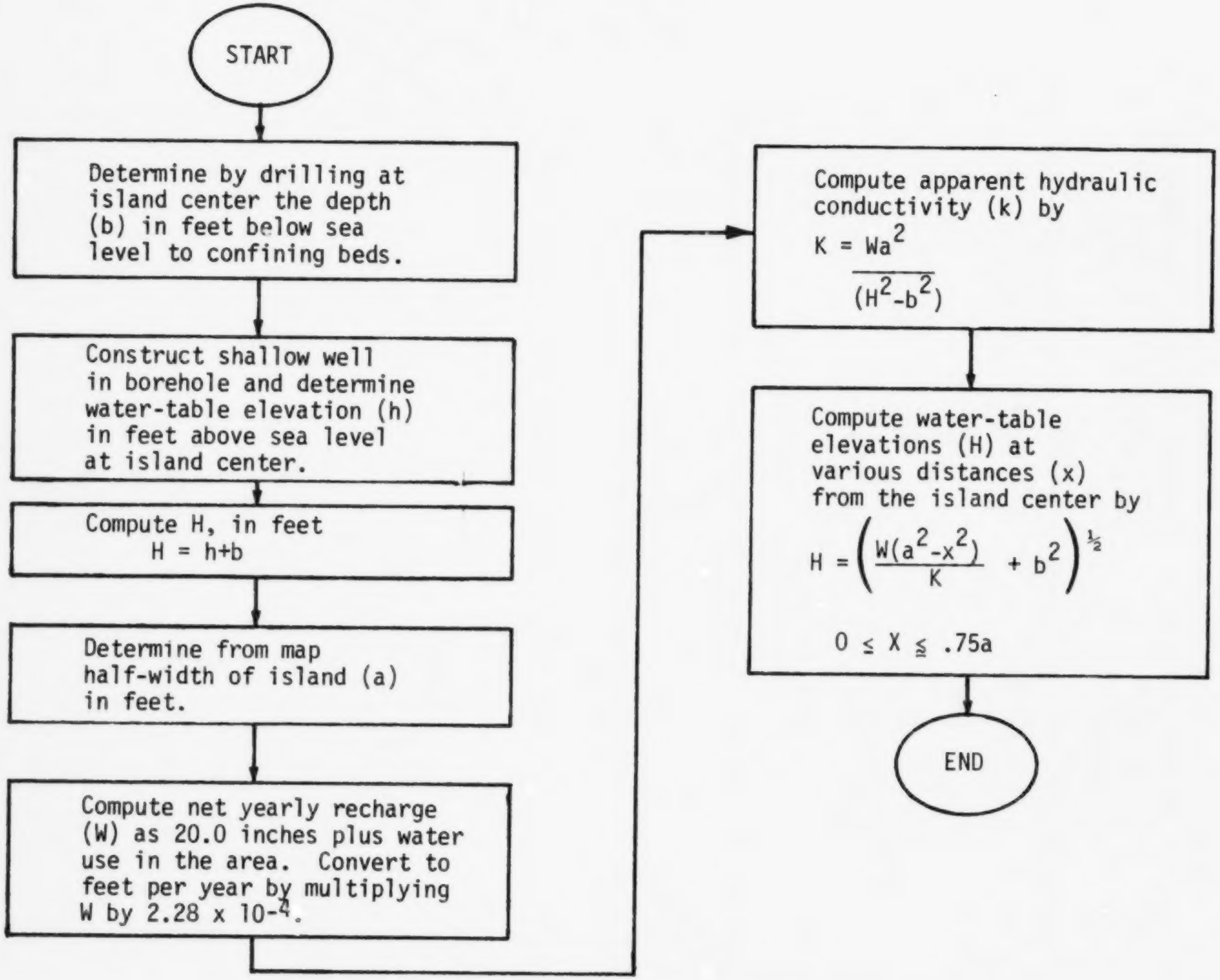

START
Determine by drilling at island center the depth (b) in feet below sea level to confining beds.
Construct shallow well in borehole and determine water-table elevation (h) in feet above sea level at island center.
Compute H, in feet
$H = h+b$
Determine from map half-width of island (a) in feet.
Compute net yearly recharge (W) as 20.0 inches plus water use in the area. Convert to feet per year by multiplying W by 2.28×10^{-4}.
Compute apparent hydraulic conductivity (k) by
$K = \frac{Wa^2}{(H^2-b^2)}$
Compute water-table elevations (H) at various distances (x) from the island center by
$H = \left(\frac{W(a^2-x^2)}{K} + b^2\right)^{\frac{1}{2}}$
$0 \leq X \leqq .75a$
END

Figure 4-2. Flow chart for computing water-table elevations.

Water-table rises greater than about four feet under current conditions in any of the study areas may cause surface flooding by ground water. Ground-water levels are generally at a depth of four feet or less below ground surface. Thus, ground-water flooding due to 24-hour rainfall events can be expected to occur with a recurrence interval between 50 and 100 years in Kill Devil Hills and Atlantic Beach/Pine Knoll Shores and with a recurrence interval between 10 and 25 years in Surf City (Table 4-5).

Increased population growth on the islands will increase the frequency of ground-water flooding. In the example given in Section 4.1.4, the 10 inches of wastewater disposal resulting from our hypothetical development will result in a 1.8-foot rise in average ground-water levels. This rise, added to rises in water levels that can be expected for the 5-year, 24-hour rainfall events, exceeds four feet in each study area. Thus, ground-water flooding will occur with some regularity in the vicinity of the hypothetical development, regardless of where on the islands this development might occur.

Although the water table rises rapidly in response to precipitation, the reverse is not true. The water table will recede quickly for one or two days after a major rainfall event and then slow to a relatively uniform recession rate. The impact on water levels of a major rainfall event, such as that which occurred in all three study areas in September 1984, will be noticeable for several weeks (see Figures 3-6, 3-19 and 3-36).

4.1.6 Alternate Approach for Model Calibration

An alternate approach for calibrating equation (3) to field conditions that may be justified involves determining an apparent hydraulic conductivity and apparent island half-width that, together, would reproduce the observed water-table elevations. This approach requires that the water-table elevation be known at two or more points along a line that extends across the width of the barrier island. A solution to equation (3) is found by trial and error such that the measured and computed water-table elevations are in approximate agreement. A comparison between apparent and computed values of hydraulic conductivity and island half-width using this alternate approach is presented in Table 4-6.

The apparent hydraulic conductivities computed using this alternate approach generally are lower than those determined by aquifer pumping tests, but are also generally in closer agreement to the measured values than the apparent hydraulic conductivities computed earlier (Table 4-1). Apparent hydraulic conductivity values lower than measured values are expected due to the effects of anisotropy (Section 4.1.2).

The apparent island half-width along each transect is greater than the measured island half-width. This is excepted. The anisotropy associated with the sand deposits, coupled with the very gently sloping shorelines on both the sound and ocean sides of the islands, suggests that freshwater discharge could be occurring some distance beyond these shorelines. The position of the subsea outflow face that defines where freshwater discharge occurs to the sound and ocean should actually be used to define the island half-width.

TABLE 4-5

WATER-TABLE RISE ASSOCIATED WITH VARIOUS RAINFALL INTENSITIES

Location	Recurrence interval (years)	24-hour rainfall[1] (inches)	Water table rise (feet)	Remarks
Kill Devil Hills	5	6.0	2.6	
	10	7.0	3.1	
	25	8.0	3.5	
	50	9.0	3.9	
	100	10.0	4.4	Probable surface flooding
Atlantic Beach/ Pine Knoll Shores	5	6.0	2.5	
	10	7.0	2.9	
	25	8.5	3.5	
	50	9.0	3.8	
	100	10.5	4.4	Probable surface flooding
Surf City	5	6.0	3.1	
	10	7.0	3.6	
	25	8.0	4.2	Probable surface flooding
	50	9.0	4.7	Probable surface flooding
	100	10.0	5.2	Probable surface flooding

(1) From Barfield et al. (1983).

TABLE 4-6

COMPARISON BETWEEN MEASURED AND APPARENT HYDRAULIC CONDUCTIVITIES AND ISLAND HALF-WIDTHS

Transect ID	Measured hydraulic conductivity (K,ft/day)	Apparent hydraulic conductivity (K_A,ft/day)	$\frac{K}{K_A}$	Measured island half-width (a,ft)	Apparent island half-width (a_A,ft)	$\frac{a}{a_A}$
K1	73	40	1.8	2060	2650	1.3
K2	73	45	1.6	2460	3150	1.3
K3	73	40	1.8	3900	4100	1.1
A1	63	25	2.5	655	950	1.5
A2	63	50	1.3	900	1080	1.2
P1	63	60	1.0	1465	2300	1.6
P2	63	300	0.2	1960	3500	1.8

Average water-table elevations computed along transects for the study period using equation (3) with calibrated apparent hydraulic conductivities and island half-widths are generally in close agreement with observed elevations (Table 4-7). The recharge values needed for these computations were taken from the water balance analyses for the transects. The aquifer thickness below sea level needed for the computations was determined from the hydrogeologic cross-sections.

The apparent hydraulic conductivities and island half-widths computed for all transects except Transect P2 in Pine Knoll Shores appear sensible. The reason for the wide discrepancy between apparent and measured values for these parameters at that location is unknown.

4.1.7 Other Models

The work plan for this project (Applied Biology, Inc., 1984) identified three simple models that might be used for computing water-table elevations. One of these models is that one described in this section. Another model is one developed by Fetter (1972) that is based on the full development of a freshwater lens surrounded by seawater beneath an island. The third model was developed using the relationship between changes in water-table elevations and changes in depth to water with a dissolved solids content of 250 milligrams per liter observed by Winner (1975) on the narrow islands that form the Cape Hatteras National Seashore.

Fetter's model (Fetter, 1972) was not applicable for use in the areas studied in this report. The shallow aquifer in each area was found to be underlain by confining beds that preclude the full development of a freshwater lens under the island.

The model developed based on Winner's observations was generally not applicable for use in the areas studied in this report. This model is based on assumptions similar to those used to develop Fetter's model.

More sophisticated ground-water models are available for computing water-table elevations. These models can be categorized generally as digital computer ground-water flow models. The use of digital computer modeling techniques was beyond the scope of this project, although sufficient data have probably been collected for constructing digital computer ground-water flow models for each study area.

4.2 Ground-Water Quality

Ground-water quality data were collected along nine transects which were selected in areas with differing levels of development. These transects were designated as high density, medium density and low density development based on a visual impression of the degree of development along each transect. The amount of wastewater disposal along each transect was also determined as a part of this study.

TABLE 4-7

COMPUTED AND OBSERVED WATER-TABLE ELEVATIONS ALONG TRANSECTS USING AN ALTERNATE APPROACH

Transect ID	Site	Net recharge (ft/day)	Aquifer thickness below sea level (feet)	Distance from island center (feet)	Computed water-table elevation (MSL)	Mean water-table elevation (MSL)	Obeserved range in water-table elevation (MSL)
Kill Devil Hills							
K1	C	.00416	55	0	6.3	6.2	5.6-7.3
	B			625	5.9	6.0	5.5-7.1
	D			800	5.7	5.1	4.5-6.3
	A			1625	4.0	4.2	3.0-7.1
	E			1875	3.2	3.1	2.2-3.4
K2	C	.00431	75	250	6.0	6.0	5.5-7.2
	D			975	5.5	6.9	6.1-8.2
	B			1200	5.2	5.0	4.3-5.8
	A			2125	3.4	3.7	2.4-5.8
	E			2450	2.4	2.0	1.6-2.4
K3	D	.00403	75	500	10.1	10.4	10.1-11.6
	C			575	10.0	9.6	9.1-10.8
	E			1575	8.8	8.4	7.2-9.6
	B			1750	8.4	6.8	6.3-7.9
	F			2450	6.6	6.2	5.9-6.8
	A			3425	3.1	3.7	2.9-5.3
	G			3550	2.5	2.0	1.8-2.1
Atlantic Beach							
A1	B	.00873	35	150	4.0	4.2	3.3-6.7
	C			225	3.9	3.9	3.0-6.0
	A			525	2.8	3.2	2.7-4.7
	D			525	2.8	2.4	1.6-3.6
A2	B	.00863	22	125	4.1	4.2	3.4-6.5
	C			505	3.3	2.6	1.9-3.4
	A			690	2.6	3.2	2.6-4.7
Pine Knoll Shores							
P1	C	.00637	50	62	5.3	5.4	4.3-7.4
	D			490	5.1	4.8	3.8-7.0
	B			650	4.9	5.1	4.2-5.9
	E			1090	4.2	3.6	3.1-5.3
	A			1250	3.8	4.3	3.5-5.3
P2	C	.00688	40	335	3.3	3.5	2.7-4.8
	D			850	3.2	2.6	2.3-3.7
	B			1275	2.9	4.0	3.4-5.5
	E			1810	2.5	2.5	1.8-3.3
	A			1860	2.4	3.2	2.3-4.2

Wastewater disposal, expressed in inches per month (in/month), is a good measure of the relative potential impact of wastewater on ground-water quality, assuming that long-term precipitation is roughly the same for each transect location. Table 4-8 presents the mean ammonia, nitrate/nitrite, MBAS and orthophosphate concentrations in ground water for each transect. Also shown in this table is the average monthly wastewater disposal for the study period. It can be seen that two of the transects have substantially lower amounts of wastewater disposal than the others. Transect K3 has wastewater disposal of 0.094 in/month and Transect P1 has 0.049 in/month. The two Atlantic Beach transects have wastewater disposal of 0.869 and 0.905 in/month and are the transects with the highest disposal rates. The remaining five transects have disposal rates which fall between the two extremes.

4.2.1 Ammonia

The data in Table 4-8 suggest that no relationship exists between the amount of wastewater disposal and the amount of ammonia found in the ground water. Figure 4-3 includes a scatter diagram upon which the wastewater disposal is plotted on the Y-axis and ammonia on the X-axis. The greatest average ammonia, 2.14 mg/l, occurs along Transect K3, which has a low wastewater disposal rate and low density of development. Pine Knoll Shores Transect P2, a low density transect, also had high ammonia even though the disposal rate was only moderate. In the Kill Devil Hills area there appears to be an inverse relationship between density of development and ammonia concentration.

The range of ammonia values is from below detection limits to as much as 17.2 mg/l (well A2A4). Some of the higher ammonia values are in brackish or saline water. If only wells with a total dissolved solids content less than 1,000 mg/l are considered, the maximum ammonia concentration is 10.70 mg/l (well P1C2).

In the wells where the ammonia content was in excess of 1.0 mg/l, it can probably be assumed that there is some impact from man's activities. Transects K3 and P2, both low density transects, and Transect A2, a high density transect, have the greatest number of ground-water analyses with an ammonia concentration greater than 1.0 mg/l. There are a number of possible sources for ammonia, including septic systems, fertilizers and animal wastes. It is not possible to pinpoint the source as wastewater, especially as there was no obvious relationship between wastewater disposal rates and ammonia.

4.2.2 Nitrate/Nitrite

Nitrate plus nitrite (nitrate/nitrite) concentration in ground water is greatest in the Surf City area, although even there it is very low (Table 4-8). There are no wells which exceed the maximum drinking water level of 10 mg/l as nitrogen for nitrate in drinking water. The greatest nitrate/nitrite concentration was 4.15 mg/l, in well S3A1. Figure 4-3 includes a scatter diagram for nitrate/nitrite concentration as a function of the amount of wastewater disposal. There is no apparent pattern to the relationship. Ninety-three percent of the analyses had nitrate/nitrite levels of less than 1.0 mg/l, a level which generally

TABLE 4-8

MEAN CONCENTRATIONS IN GROUND WATER OF SELECTED COMPOUNDS[1]

Transect ID	Density of development	Wastewater disposal rate (in./month)	Ammonia	Nitrate/ nitrite	MBAS	Ortho-phosphate
Kill Devil Hills						
K1	Medium	0.141	0.70	0.33	0.024	0.27
K2	High	0.196	0.39	0.28	0.09	0.36
K3	Low	0.094	2.14	0.06	0.005	0.54
Atlantic Beach						
A1	High	0.905	1.27	0.12	0.034	0.78
A2	High	0.869	2.09	0.19	0.076	0.18
Pine Knoll Shores						
P1	Medium	0.049	0.97	0.005	0.44	0.81
P2	Low	0.253	2.04	0.03	0.02	1.55
Surf City						
S1	Medium	0.493	1.24	0.62	0.022	0.22
S3	High	0.413	1.14	0.37	0.008	0.46

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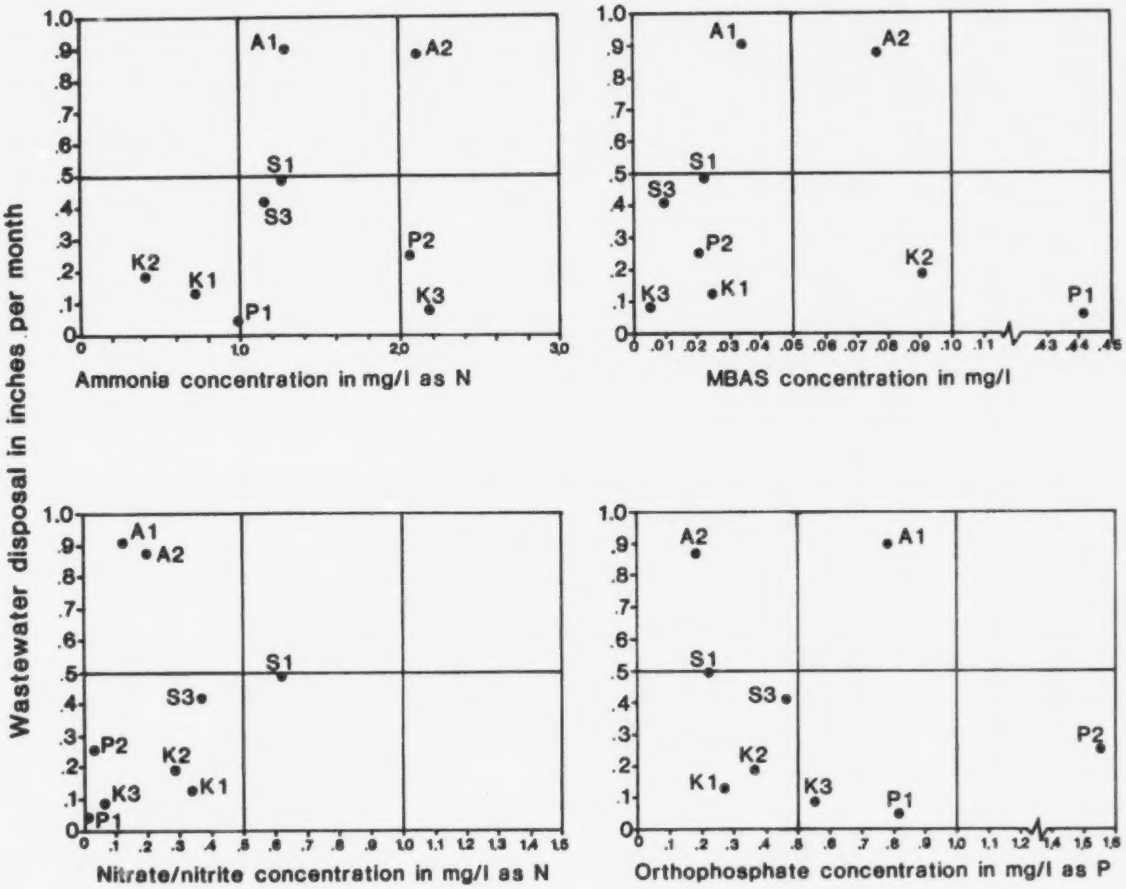
(1)All values are reported in mg/l.



EXPLANATION

Transect - S3 ● Mean concentration of selected compound along transect

Figure 4-3. Comparison between wastewater disposal rate and mean concentration in water of selected compounds.

indicates no impact due to wastewater disposal. Only one well, S1A1, had nitrate/nitrite above 1.0 mg/l every time that the well was sampled. There is no apparent impact of wastewater disposal, or other activity, on nitrate/nitrite levels other than at well S1A1.

4.2.3 MBAS

There is a maximum contaminant level for drinking water of 0.5 mg/l MBAS, which is a measure of detergent in water. This standard was exceeded in wells K2A1 (0.53 mg/l) and K2D1 (0.50 mg/l). In both cases there were three other analyses at the well which were below the standard. Figure 4-3 includes a scatter diagram of MBAS concentration as a function of the amount of wastewater recharge. There is no apparent relationship between the two variables. No MBAS were detected in 48 percent of the samples analyzed. In the remaining 52 percent of the samples, MBAS were detected, but generally in very low amounts. The usefulness of the ground water has not been impaired by MBAS, except perhaps at wells K2A1 and K2D1.

4.2.4 Orthophosphate

Orthophosphate is a soluble form of phosphorous which can come from a number of sources, including wastewater. Phosphate in surface water is a nutrient which can cause eutrophication if the waters are phosphate-limited. There is no drinking water standard for phosphorous.

Figure 4-3 includes a scatter diagram which shows mean orthophosphate concentration along each transect as a function of wastewater disposal. As with the other compounds, there does not appear to be any relationship between the two variables. Only one quarter of the samples exceed 0.50 mg/l orthophosphate. The greatest orthophosphate value was 6.34 mg/l, in well P1D1. In the Pine Knoll Shores area, 13 of 36 analyses exceeded 1.0 mg/l. The greatest mean value was 1.55 mg/l along Transect P2, a low density transect. Both of the Pine Knoll Shores transects had phosphate levels greater than either of the Atlantic Beach transects, although the Atlantic Beach transects had much higher rates of wastewater disposal and were both high density.

There does not appear to be any relationship between the occurrence of ammonia and orthophosphate. Transect P2 had both relatively high ammonia (2.04 mg/l) and relatively high phosphate (1.55 mg/l). Transect A2 had relatively high ammonia (2.09 mg/l) but relatively low phosphate (0.18 mg/l). The terms high and low are used here for comparison purposes only and are not meant to imply high values in an absolute sense.

4.2.5 Fecal Coliform Bacteria

Fecal coliform bacteria were present in some of the samples from all of the study areas. In Kill Devil Hills there were two samples with coliforms. At Surf City 10 of 61 samples had coliforms. Six out of 36 analyses in Pine Knoll Hills had coliforms. Atlantic Beach had the highest occurrence, with 33 of 90 samples showing coliforms. There is evidence that some of these coliforms originated from surface flooding during periods of heavy precipitation. This may have impacted up to 12 of the 33 samples which had coliforms.

Coliform bacteria occur in areas of high, medium and low density of development. However, there is a definite pattern, with the areas of highest wastewater disposal, A1, A2, S1 and S3, all having the highest percentage of wells with coliforms present. As some of these wells were impacted by flooding and not subsequently disinfected, the coliform data should be interpreted with care. Some of the positive coliform tests may have been caused by coliforms which were introduced into the ground water by the flooded water.

4.2.6 Variation of Chemical Quality with Depth

At a number of locations well clusters were installed in order to enable water samples to be withdrawn at various depths. One outcome of this type of sampling is the ability to locate the saltwater interface and zone of diffusion. The following parameters typically increase with depth in the study areas and indicate the presence of brackish or salt water: sodium, chloride, total dissolved solids and specific conductance. Hardness may also increase with depth if brackish and/or salty water which may contain increased calcium and/or magnesium is encountered. Alkalinity appears to have no relationship with either depth or salinity.

A detailed analysis has been made of the four water chemistry parameters (MBAS, ammonia, nitrate plus nitrite and orthophosphate) which might be affected by waste water disposal. Mean values of each parameter for each well in a cluster were computed. Some wells only had one measurement and others had up to five. Well cluster S3B had two wells, S3B1 and S3B5, with only one analysis, whereas the other three wells in the cluster each had four analyses. In this case, only the wells with four analyses were used.

The mean values for each cluster were compared and classified into one of four categories:

1. Constant: Mean values varied by no more than 10 percent in each well.
2. Decreasing: The uppermost well had the greatest value and was at least 10 percent greater than any other value.
3. Increasing: The deepest well had the greatest value and was at least 10 percent greater than any other value.
4. Variable: All other wells.

Table 4-9 illustrates results of this exercise.

Of the four parameters, only ammonia has a clear pattern; that of increasing with depth (62 percent of the well clusters). MBAS and nitrate plus nitrite decreased with depth in 38 percent of the wells, which was more than any other pattern. Orthophosphate had a variable pattern more than half of the time.

TABLE 4-9

VARIATION OF CHEMICAL QUALITY WITH DEPTH

	Well clusters	MBAS				Ammonia				Nitrate/Nitrite				Orthophosphate			
		Consistent	Decreases	Increases	Variable	Consistent	Decreases	Increases	Variable	Consistent	Decreases	Increases	Variable	Consistent	Decreases	Increases	Variable
Kill Devil Hills	Number	3	5	1	2	0	2	5	4	2	6	2	1	0	4	2	5
	Percent	27	45	9	18	0	18	45	36	18	55	18	9	0	36	18	45
Atlantic Beach	Number	0	3	3	1	0	1	5	1	1	1	4	1	1	1	4	1
	Percent		43	43	14	0	14	72	14	14	14	58	14	14	14	58	14
Pine Knoll Shores	Number	1	2	2	1	0	0	4	2	5	0	1	0	0	1	0	5
	Percent	17	33	33	17	0	0	67	33	83	0	17	0	0	17	0	83
Surf City	Number	1	2	1	1	0	0	4	1	0	4	0	1	0	1	0	4
	Percent	20	40	20	20	0	0	80	20	0	80	0	20	0	20	0	80
Total	Number	5	11	7	6	0	3	18	8	8	11	7	3	1	7	6	15
	Percent	17	38	24	21	0	10	62	28	28	38	24	10	3	24	21	52

Three of the four study areas had no particular pattern for all of the parameters. However, at Atlantic Beach chemical concentrations increased with depth in more than half of the wells for ammonia, nitrate plus nitrite and orthophosphate. Atlantic Beach is also the area with the greatest percentage of wastewater recharge.

There is no obvious explanation for the consistent pattern of increasing ammonia concentrations with depth.

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APPENDIX A

WELL CONSTRUCTION RECORDS

Well construction records have been completed for each well site in each study area. These records are presented on the following pages. The symbols used in these records are identified in Figure 1.

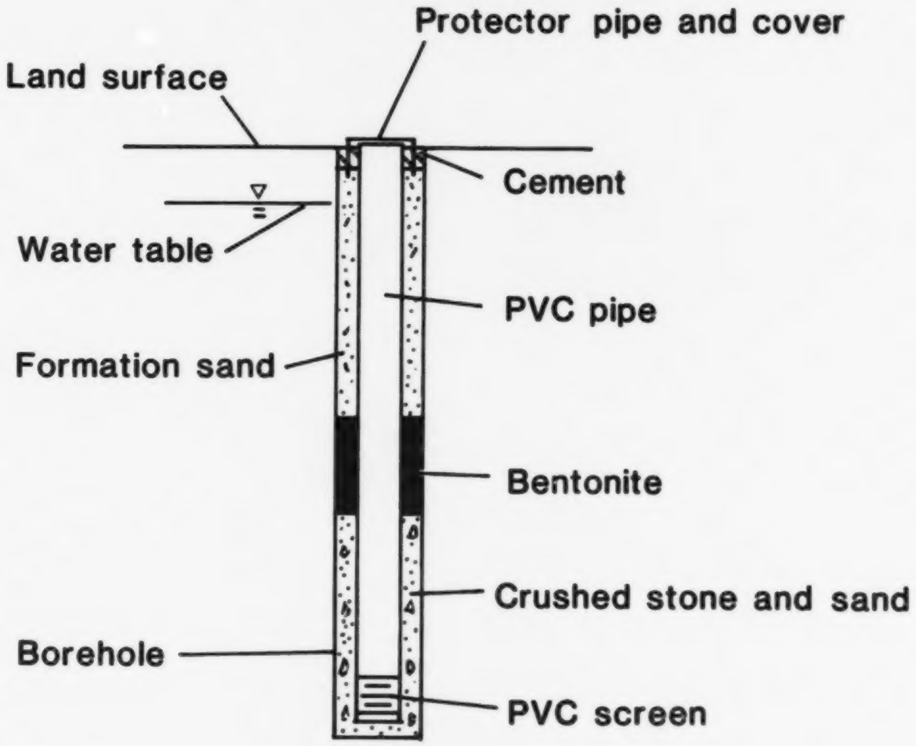
Protector pipe and cover
Land surface
Cement
Water table
PVC pipe
Formation sand
Bentonite
Crushed stone and sand
Borehole
PVC screen

Figure 1. Identification of symbols used in well construction records.

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WELL CONSTRUCTION RECORDS

FOR

KILL DEVIL HILLS

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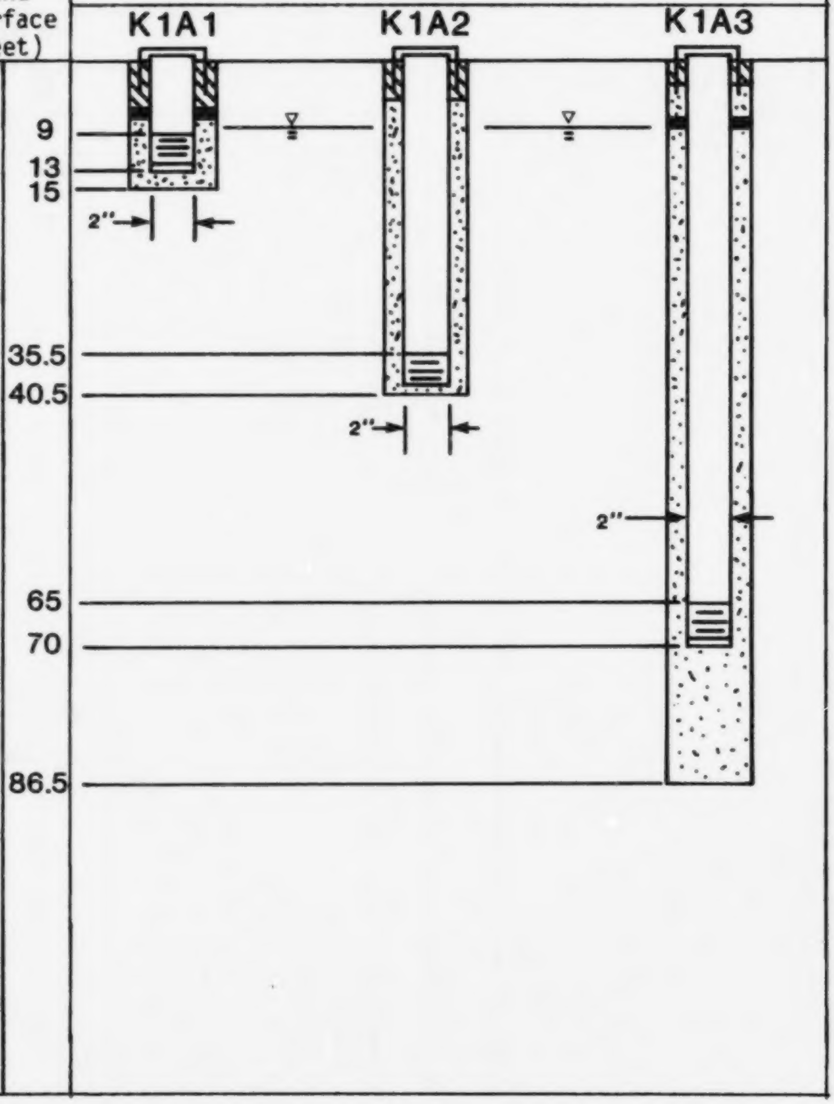
WELL CONSTRUCTION RECORD

Site ID: K1A
Client: EPA
Location: Kill Devil Hills, NC
Project No.: 172
Geologist: T. Corwin, J. Fish

Well construction: The wells are constructed of schedule 40 PVC pipe and are finished about one foot above land surface. The wells are enclosed at land surface in steel pipes with locking caps.

Predominant Lithology	Depth below land surface (feet)
Tan to brown medium sand	25
Gray to brown medium to fine sand	40
Dense to very dense gray fine sand	75
Gray fine sand with some clay	80
Silt and sand	

Well Construction Details



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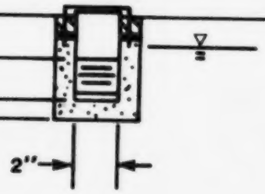
WELL CONSTRUCTION RECORD

Site ID: K1B Client: EPA Location: Kill Devil Hills, NC Project No.: 172 Geologist: T. Corwin	Well construction: The well is constructed of schedule 40 PVC pipe and is finished about one foot above land surface. The well is enclosed at land surface in a steel pipe with a locking cap.

Predominant Lithology	Depth below land surface (feet)		Well Construction Details
			K1B1
Brown fine to medium sand		5	
Light gray fine sand	6	10 12	

WELL CONSTRUCTION RECORD

Site ID: K1C

Client: EPA

Location: Kill Devil Hills, NC

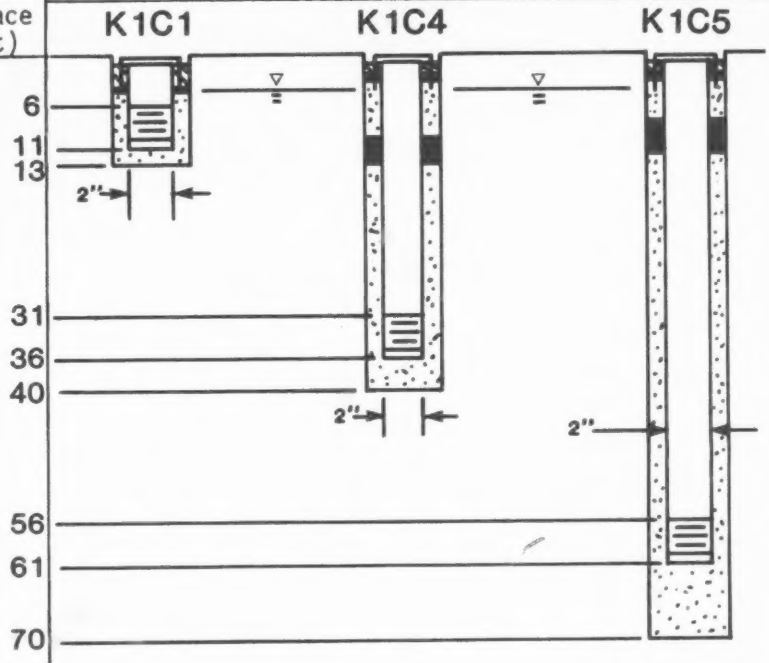
Project No.: 172

Geologist: T. Corwin, J. Fish

Well construction: The wells are constructed of schedule 40 PVC pipe and are finished at land surface in utility boxes. The wells are enclosed at land surface in steel pipes with locking caps.

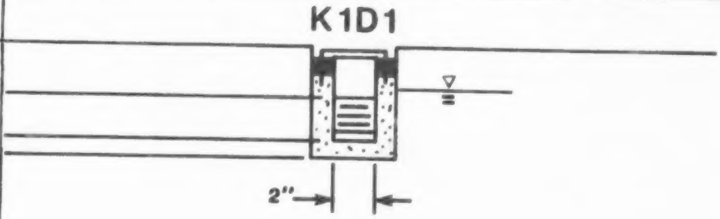
Predominant Lithology	Depth below land surface (feet)
Light brown fine to medium sand	
	10
Peat	
	12
Dense light gray fine to medium sand	
	65
Silty fine sand	

Well Construction Details



WELL CONSTRUCTION RECORD

Site ID: K1D	Well construction: The well is constructed of schedule 40 PVC pipe and is finished at land surface in a utility box. The well is enclosed at land surface in a steel pipe with a locking cap.
Client: EPA	
Location: Kill Devil Hills, NC	
Project No.: 172	
Geologist: T. Corwin	

Predominant Lithology	Depth below land surface (feet)	Well Construction Details
Light brown fine to medium sand	6 11 13	

WELL CONSTRUCTION RECORD

Site ID: K1E

Client: EPA

Location: Kill Devil Hills, NC

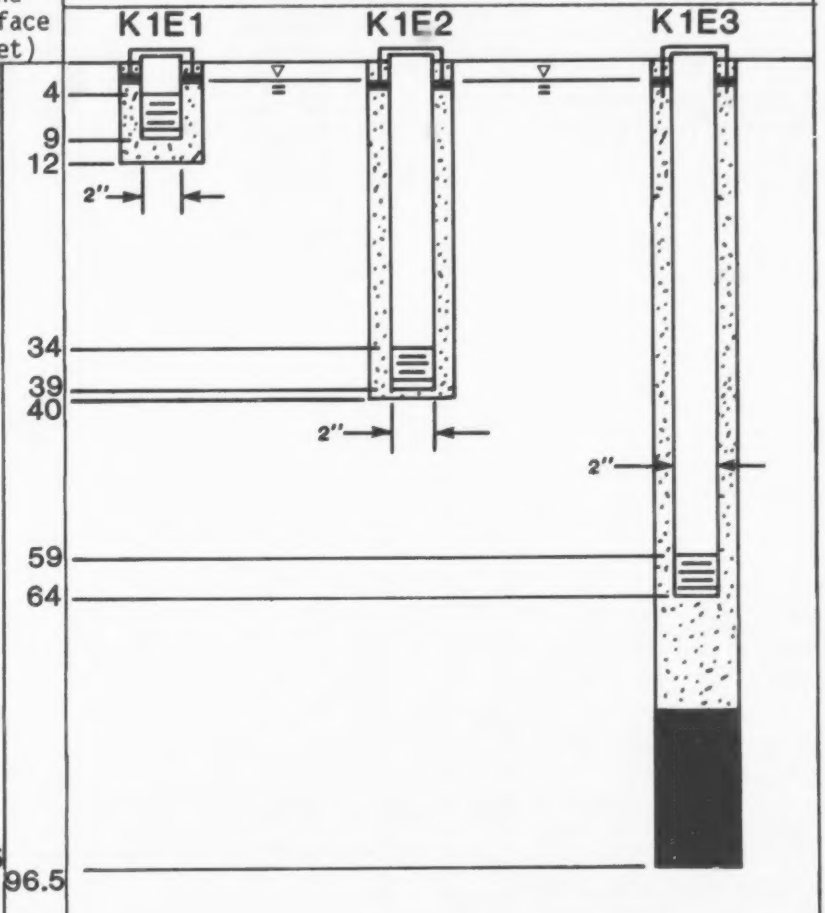
Project No.: 172

Geologist: T. Corwin, J. Fish

Well construction: The wells are constructed of schedule 40 PVC pipe and are finished about one foot above land surface. The wells are enclosed at land surface in steel pipes with locking caps.

Predominant Lithology	Depth below land surface (feet)
Organic silt	3.5
Loose to firm light gray fine sand	35
Firm to dense light gray fine to medium sand with some shell fragments	55
Firm to very dense gray fine to medium sand	75
Gray silty fine sand	95.5
Very dense gray fine sand	

Well Construction Details



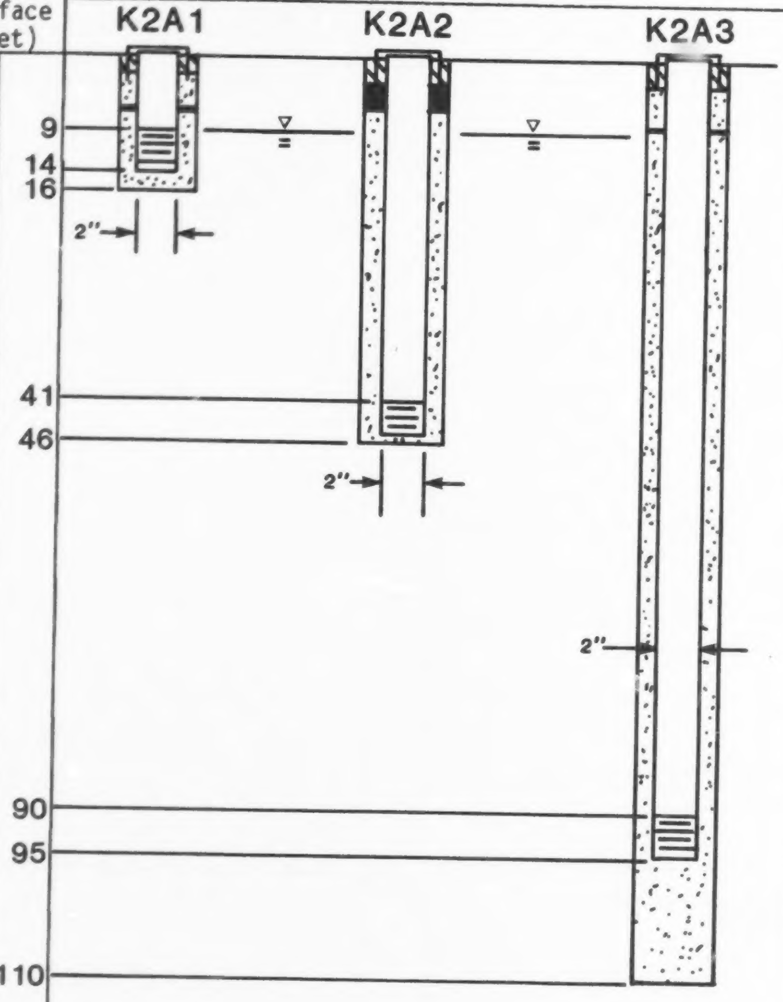
WELL CONSTRUCTION RECORD

Site ID:	K2A
Client:	EPA
Location:	Kill Devil Hills, NC
Project No.:	172
Geologist:	T. Corwin, J. Fish

Well construction: The wells are constructed of schedule 40 PVC pipe and are finished about one foot above land surface. The wells are enclosed at land surface in steel pipes with locking caps.

Predominant Lithology	Depth below land surface (feet)
Firm to very dense fine to coarse tan sand	45
Fine to very dense fine gray sand	65
Very dense tan fine sand with some clay and silty sand lenses	80
Very dense gray fine to coarse sand	90
Lenses of white, tan and black medium to coarse sand and clay	97
Lenses of fine sand and clay	102
Fine to coarse sand with shells	

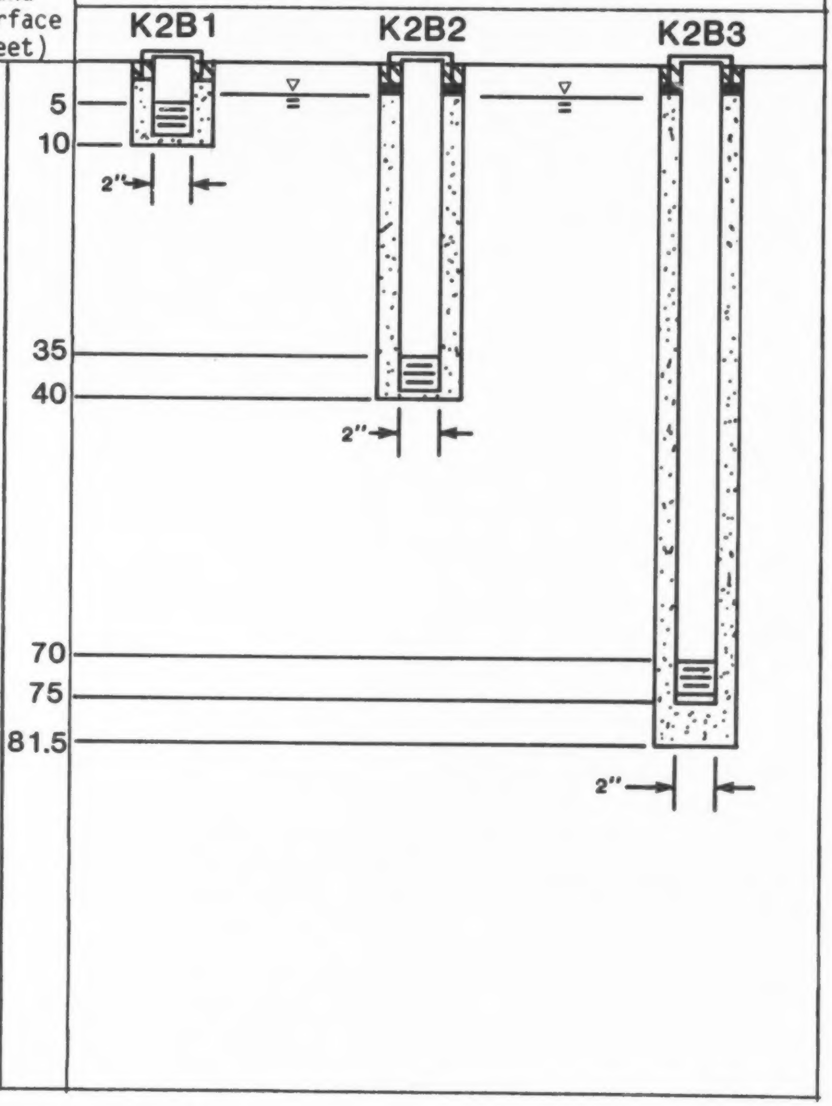
Well Construction Details



WELL CONSTRUCTION RECORD

Site ID: K2B
Client: EPA
Location: Kill Devil Hills, NC
Project No.: 172
Geologist: T. Corwin, J. Fish

Well construction: The wells are constructed of schedule 40 PVC pipe and are finished about one foot above land surface. The wells are enclosed at land surface in steel pipes with locking caps.

Predominant Lithology	Depth below land surface (feet)	Well Construction Details
Light brown fine to medium sand	10	 K2B1 K2B2 K2B3 5 10 35 40 70 75 81.5 2" 2" 2"
Dense to very dense light gray fine to medium sand	77	
Interbedded clayey silts and silty fine sand		

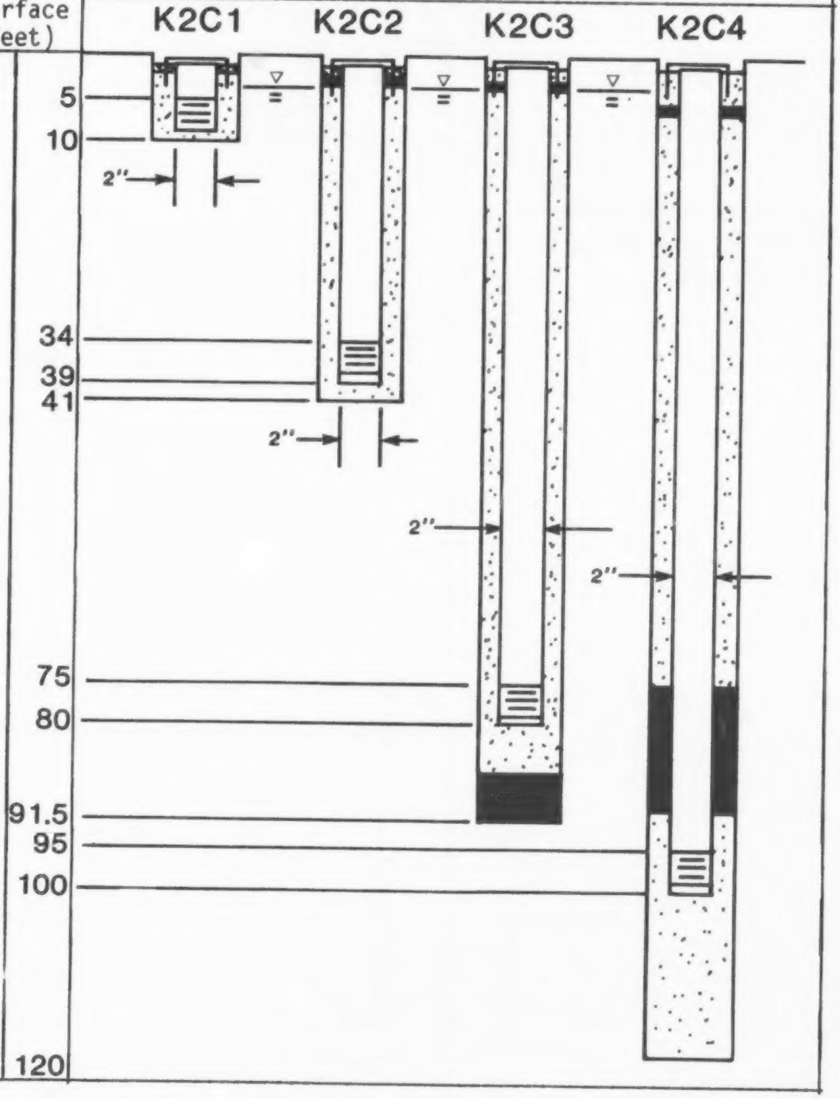
WELL CONSTRUCTION RECORD

Site ID: K2C
Client: EPA
Location: Kill Devil Hills, NC
Project No.: 172
Geologist: T. Corwin, J. Fish

Well construction: The wells are constructed of schedule 40 PVC pipe and are finished at land surface in utility boxes. The wells are enclosed at land surface in steel pipes with locking caps.

Predominant Lithology	Depth below land surface (feet)
Light brown medium sand	5
Light gray fine to medium sand	35
Very dense light gray fine sand with shell fragments	60
Firm to very dense light gray fine to medium sand	85
Stiff gray sandy silt	91
Green to gray coarse sand	

Well Construction Details



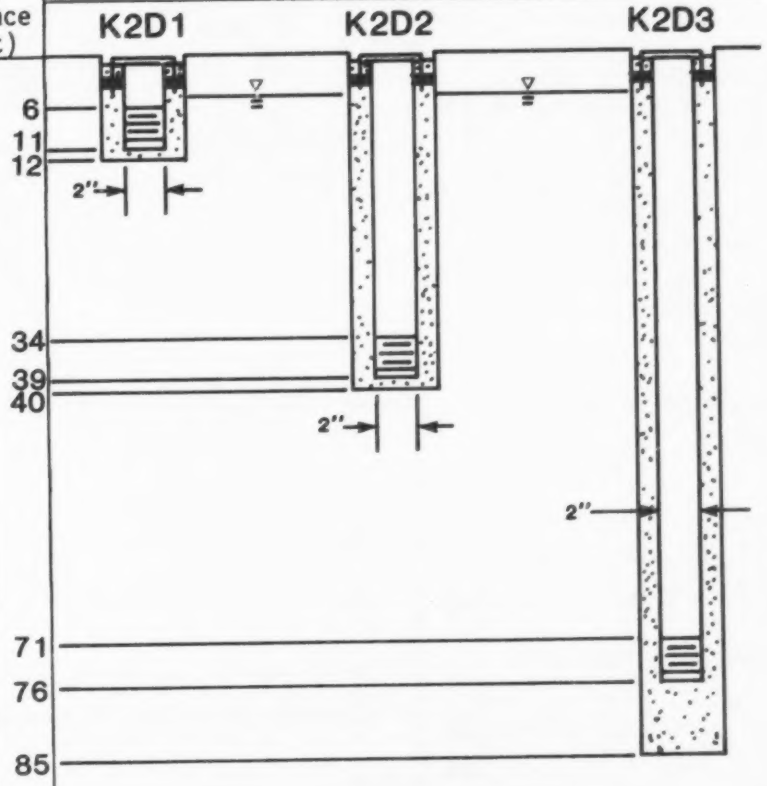
WELL CONSTRUCTION RECORD

Site ID: K2D
Client: EPA
Location: Kill Devil Hills, NC
Project No.: 172
Geologist: T. Corwin, J. Fish

Well construction: The wells are constructed of schedule 40 PVC pipe and are finished at land surface in utility boxes. The wells are enclosed at land surface in steel pipes with locking caps.

Predominant Lithology	Depth below land surface (feet)
Light brown fine sand	5
Light gray fine sand	19
Clayey silt and silty sand	22
Light gray fine to medium sand	50
Gray fine to medium sand with shells	81
Silt with some clay	

Well Construction Details



WELL CONSTRUCTION RECORD

Site ID: K2E

Client: EPA

Location: Kill Devil Hills, NC

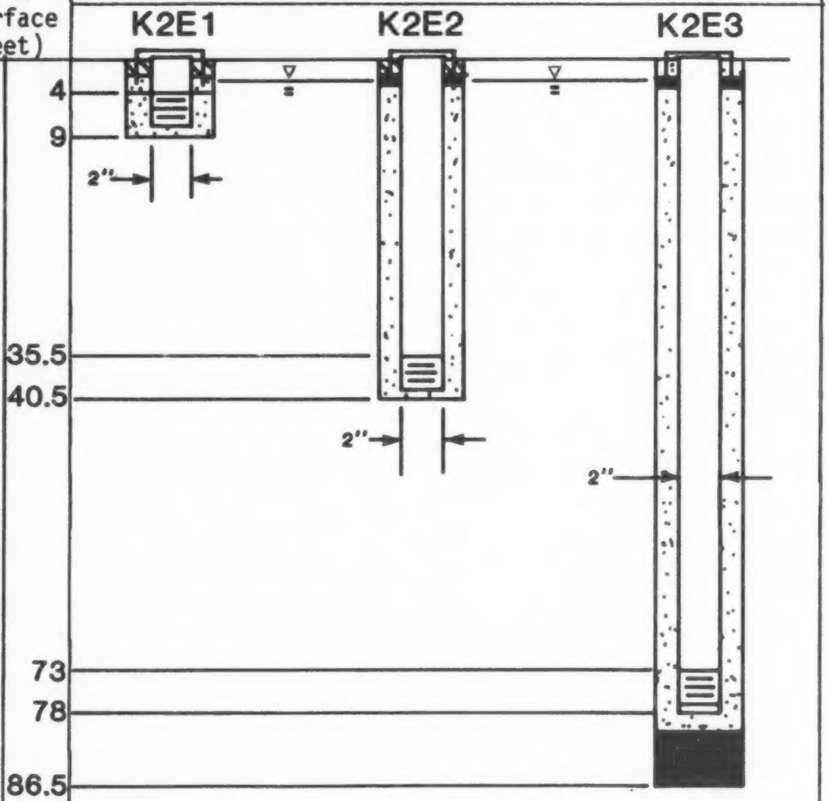
Project No.: 172

Geologist: T. Corwin, J. Fish

Well construction: The wells are constructed of schedule 40 PVC pipe and are finished about one foot above land surface. The wells are enclosed at land surface in steel pipes with locking caps.

Predominant Lithology	Depth below land surface (feet)
Brown fine to medium sand with thin lenses of peat	5
Gray fine sand	15
Gray fine sand with some silt	25
Gray fine to medium sand	55
Silt and silty fine sand	65
Light gray fine sand	81
Silty clay	85
Firm blue-gray clay	

Well Construction Details



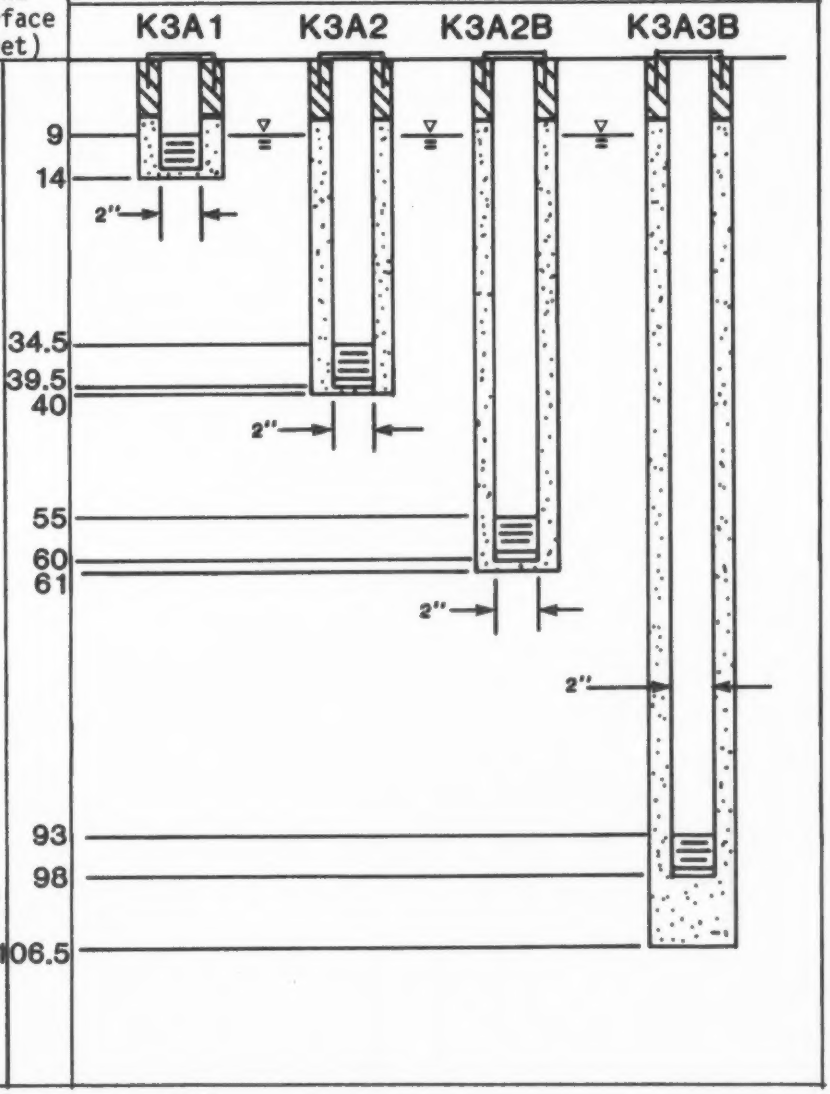
WELL CONSTRUCTION RECORD

Site ID:	K3A
Client:	EPA
Location:	Kill Devil Hills, NC
Project No.:	172
Geologist:	T. Corwin, J. Fish

Well construction: The wells are constructed of schedule 40 PVC pipe and are finished about one foot above land surface. The wells are enclosed at land surface in steel pipes with locking caps.

Predominant Lithology	Depth below land surface (feet)
Light brown medium sand	5
Light brown fine to medium sand with shell fragments	25
Gray fine sand with shell fragments	35
Gray fine sand with a trace of silt	60
Very dense light gray fine sand	70
Very dense light gray medium to coarse sand	100
Silty sand	

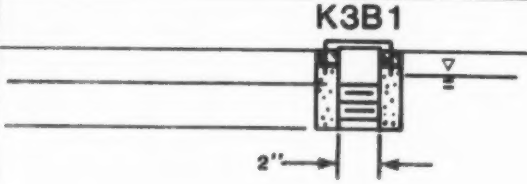
Well Construction Details



WELL CONSTRUCTION RECORD

Site ID: K3B
Client: EPA
Location: Kill Devil Hills, NC
Project No.: 172
Geologist: T. Corwin, J. Fish

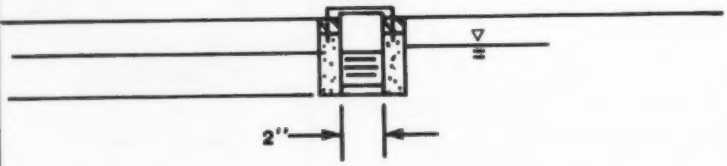
Well construction: The well is constructed of schedule 40 PVC pipe and is finished about one foot above land surface. The well is enclosed at land surface in a steel pipe with a locking cap.

Predominant Lithology	Depth below land surface (feet)		Well Construction Details
Light brown fine to medium sand	3	4 9	
Gray fine to medium sand			

WELL CONSTRUCTION RECORD

Site ID: K3C
Client: EPA
Location: Kill Devil Hills, NC
Project No.: 172
Geologist: T. Corwin, J. Fish

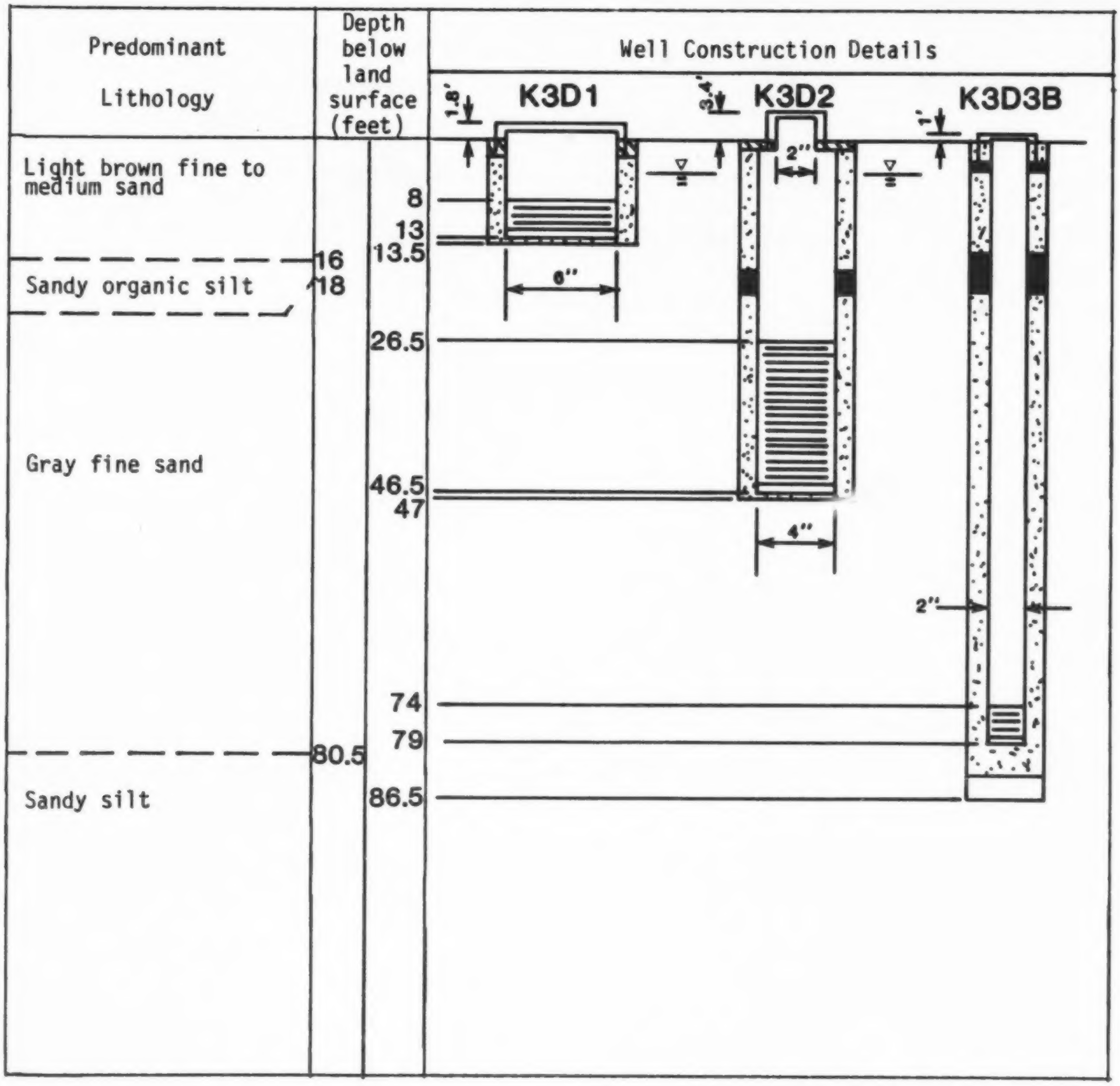
Well construction: The well is constructed of schedule 40 PVC pipe and is finished about one foot above land surface. The well is enclosed at land surface in a steel pipe with a locking cap.

Predominant Lithology	Depth below land surface (feet)	Well Construction Details
Light brown fine to medium sand	4 9	**K3C1** 

WELL CONSTRUCTION RECORD

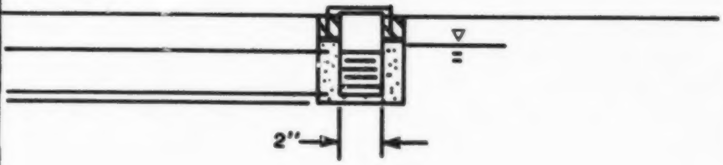
Site ID:	K3D
Client:	EPA
Location:	Kill Devil Hills, NC
Project No.:	172
Geologist:	T. Corwin, J. Fish

Well construction: The wells are constructed of schedule 40 PVC pipe. The wells are enclosed at land surface in steel pipes with locking caps.


Predominant Lithology
Depth below land surface (feet)
Well Construction Details
K3D1
K3D2
K3D3B
1.8'
3.4'
1'
Light brown fine to medium sand
Sandy organic silt
Gray fine sand
Sandy silt
16
18
80.5
8
13
13.5
26.5
46.5
47
74
79
86.5
6"
2"
4"
2"

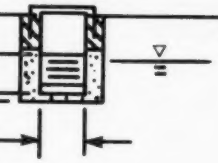
WELL CONSTRUCTION RECORD

Site ID: K3E	Well construction: The well is constructed of schedule 40 PVC pipe and is finished about one foot above land surface. The well is enclosed at land surface in a steel pipe with a locking cap.
Client: EPA	
Location: Kill Devil Hills, NC	
Project No.: 172	
Geologist: T. Corwin, J. Fish	

Predominant Lithology	Depth below land surface (feet)		Well Construction Details K3E1
Brown fine to medium sand	6.5	4.5 9.5 10	
Gray fine to medium sand			

WELL CONSTRUCTION RECORD

Site ID: K3F	Well construction: The well is constructed of schedule 40 PVC pipe and is finished about one foot above land surface. The well is enclosed at land surface in a steel pipe with a locking cap.
Client: EPA	
Location: Kill Devil Hills, NC	
Project No.: 172	
Geologist: T. Corwin, J. Fish	

Predominant Lithology	Depth below land surface (feet)	Well Construction Details
		K3F1
Light brown fine to medium sand	6 11 12	

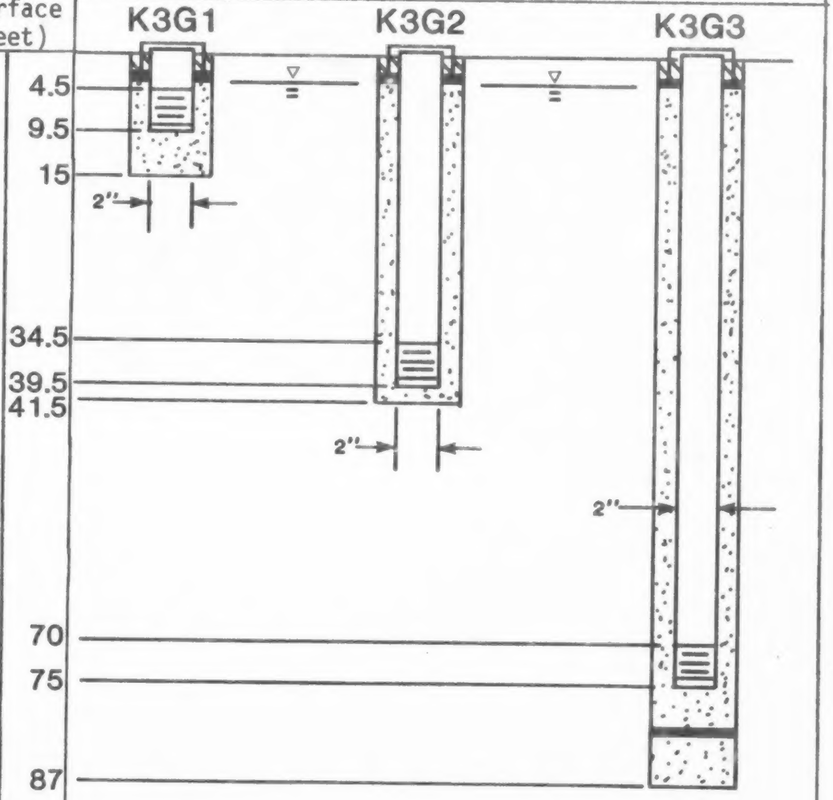
WELL CONSTRUCTION RECORD

Site ID: K3G
Client: EPA
Location: Kill Devil Hills, NC
Project No.: 172
Geologist: T. Corwin, J. Fish

Well construction: The wells are constructed of schedule 40 PVC pipe and are finished about one foot above land surface. The wells are enclosed at land surface in steel pipes with locking caps.

Predominant Lithology	Depth below land surface (feet)
Light brown fine sand	10
Light gray fine sand	25
Light gray fine sand with shell fragments	40
Light gray to brown fine to medium sand	65
Gray fine sand with clayey sand and silty sand lenses	81
Clayey silt	

Well Construction Details



WELL CONSTRUCTION RECORDS

FOR

ATLANTIC BEACH

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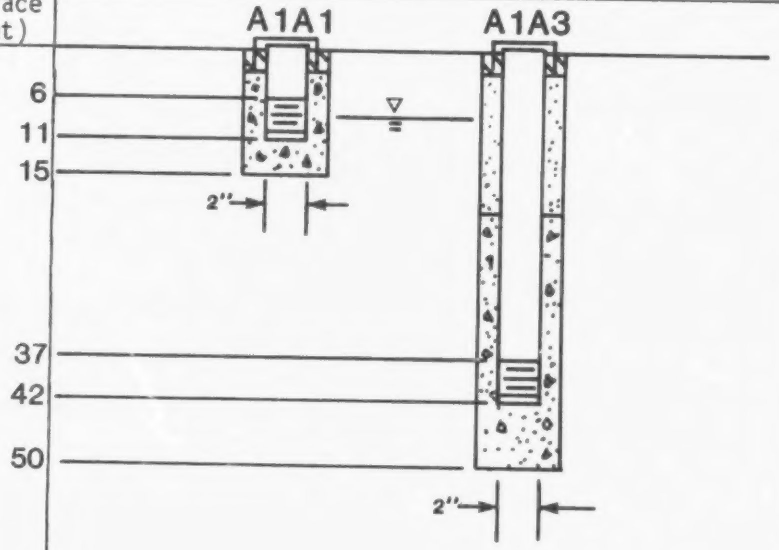
WELL CONSTRUCTION RECORD

Site ID:	A1A
Client:	EPA
Location:	Atlantic Beach, NC
Project No.:	172
Geologist:	T. Corwin, J. Fish

Well construction: The wells are constructed of schedule 40 PVC pipe and are finished about one foot above land surface. The wells are enclosed at land surface in steel pipes with locking caps.

Predominant Lithology	Depth below land surface (feet)
Tan fine to medium sand	
	9
Gray fine to medium sand	
	20
Gray fine to medium sand and shells	
	46
Soft gray clay	

Well Construction Details



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WELL CONSTRUCTION RECORD

Site ID: A1B

Client: EPA

Location: Atlantic Beach, NC

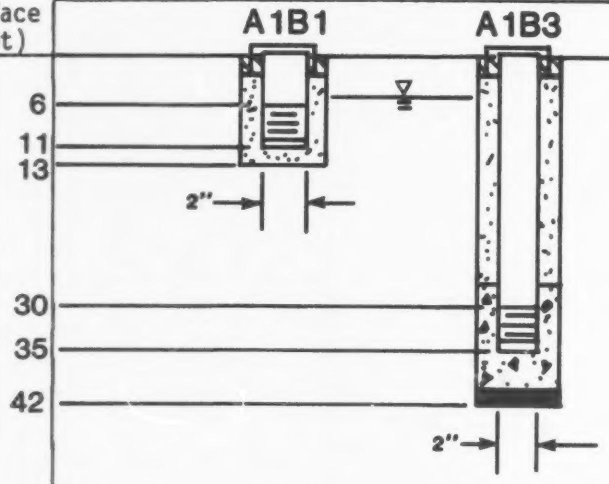
Project No.: 172

Geologist: T. Corwin, J. Fish

Well construction: The wells are constructed of schedule 40 PVC pipe and are finished about one foot above land surface. The wells are enclosed at land surface in steel pipes with locking caps.

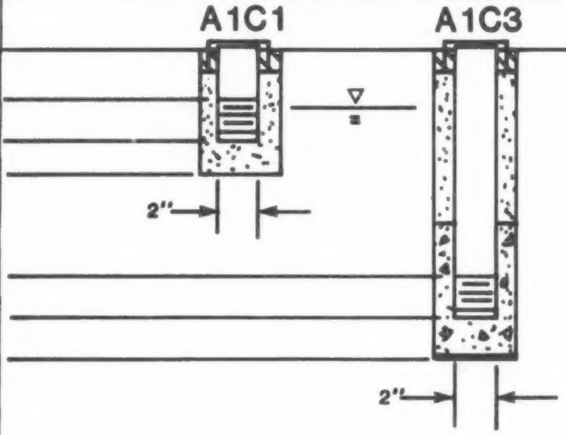
Predominant Lithology	Depth below land surface (feet)
Tan fine sand	
	12
Gray silty fine sand	
	24
Tan to gray fine sand and shells	
	36
Gray clay and silt	
	40.5
Silty fine sand	

Well Construction Details



WELL CONSTRUCTION RECORD

Site ID:	A1C	Well construction: The wells are constructed of schedule 40 PVC pipe and are finished about one foot above land surface. The wells are enclosed at land surface in steel pipes with locking caps.
Client:	EPA	
Location:	Atlantic Beach, NC	
Project No.:	172	
Geologist:	T. Corwin	

Predominant Lithology	Depth below land surface (feet)		Well Construction Details
Tan fine to medium sand and shells		6	
	12	11	
Interbeded layers of fine sand and silty fine sand		15	
	24		
Gray fine sand and shells		27	
	32	32	
Gray silty fine sand		37	

WELL CONSTRUCTION RECORD

Site ID: A1D

Client: EPA

Location: Atlantic Beach, NC

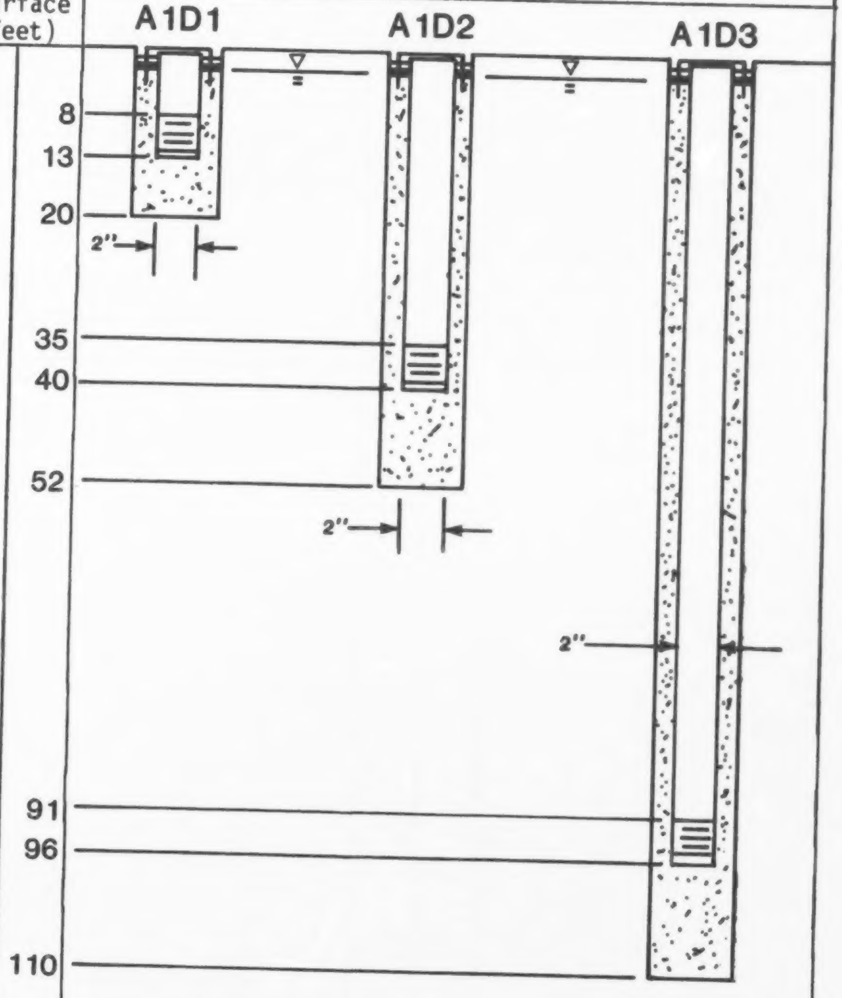
Project No.: 172

Geologist: J. Fish

Well construction: The wells are constructed of schedule 40 PVC pipe and are finished at land surface in utility boxes. The wells are enclosed at land surface in steel pipes with locking caps.

Predominant Lithology	Depth below land surface (feet)
Fine sand and gravel (fill)	7
Gray fine sand	18
Gray fine sand with some shells	49
Gray clay interbedded with fine sand[1]	52
Gray fine sand with shells	70
Tan fine to coarse sand and shells	

Well Construction Details



[1] This layer was encountered only in borehole A1D2.

WELL CONSTRUCTION RECORD

Site ID: A2A

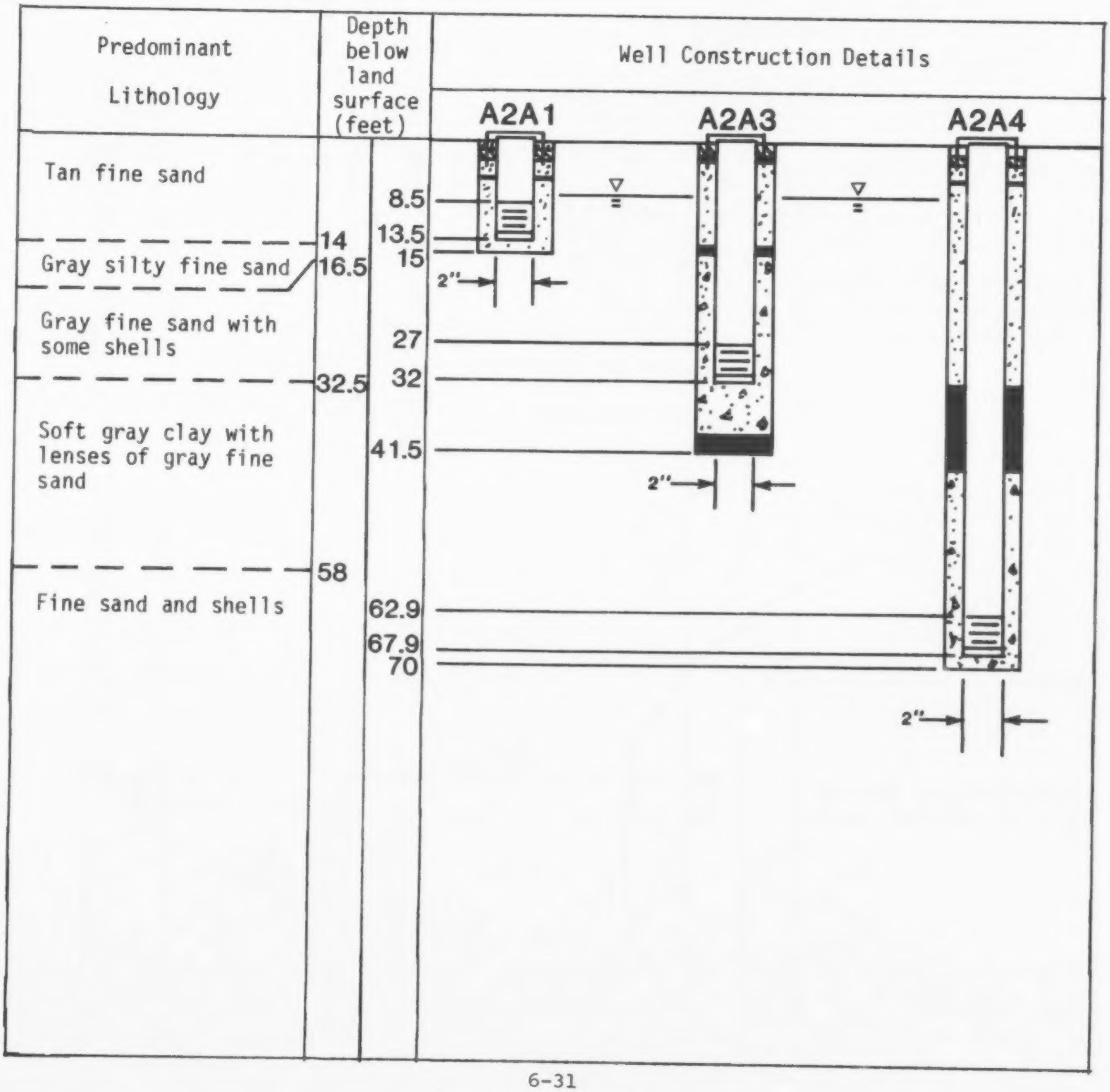
Client: EPA

Location: Atlantic Beach, NC

Project No.: 172

Geologist: T. Corwin, J. Fish

Well construction: The wells are constructed of schedule 40 PVC pipe and are finished about one foot above land surface. The wells are enclosed at land surface in steel pipes with locking caps.



Predominant Lithology
Depth below land surface (feet)
Well Construction Details
A2A1
A2A3
A2A4
Tan fine sand
8.5
14
13.5
Gray silty fine sand
16.5
15
2"
Gray fine sand with some shells
27
32.5
32
Soft gray clay with lenses of gray fine sand
41.5
2"
58
Fine sand and shells
62.9
67.9
70
2"

WELL CONSTRUCTION RECORD

Site ID: A2B

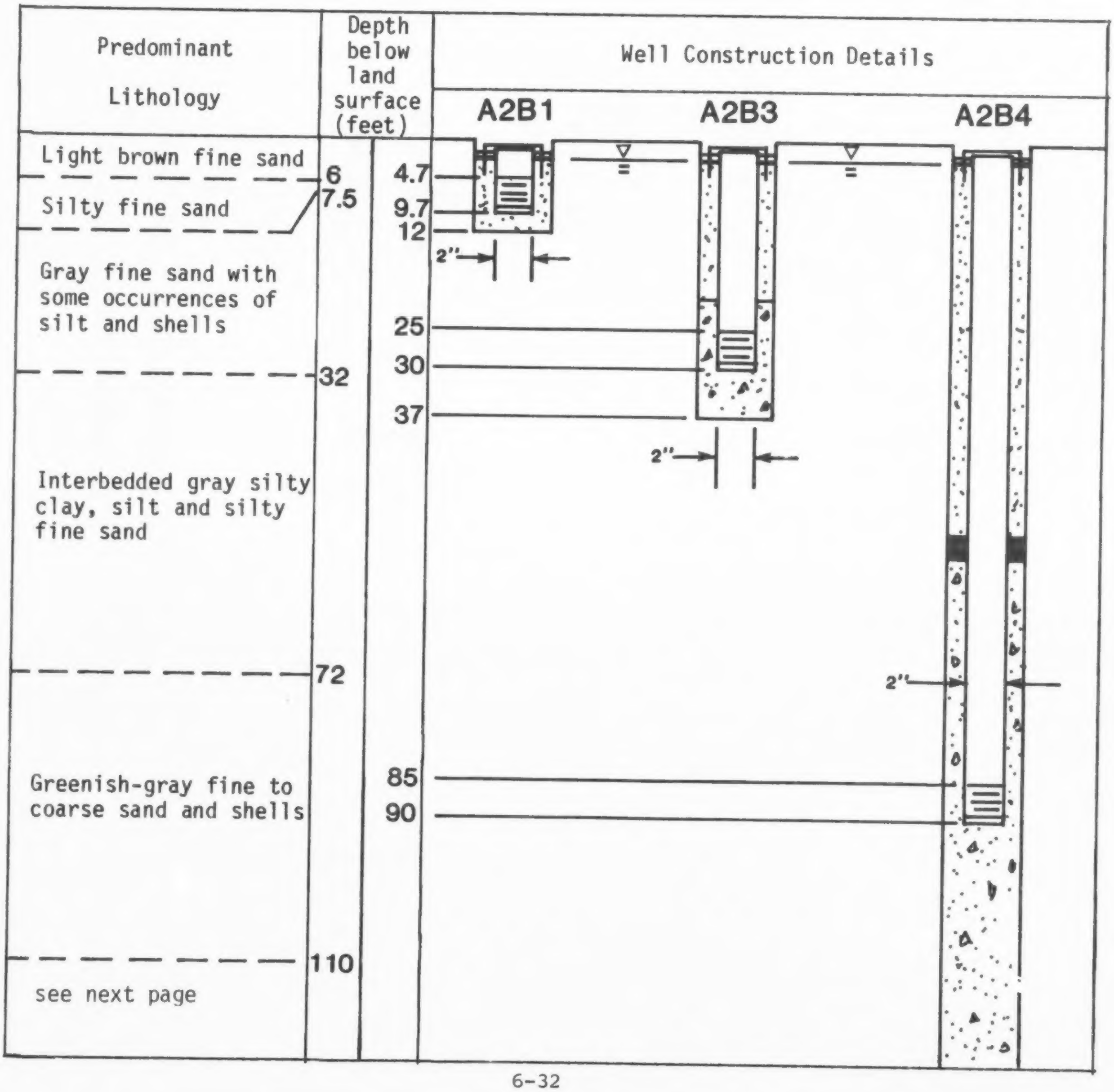
Client: EPA

Location: Atlantic Beach, NC

Project No.: 172

Geologist: T. Corwin, J. Fish

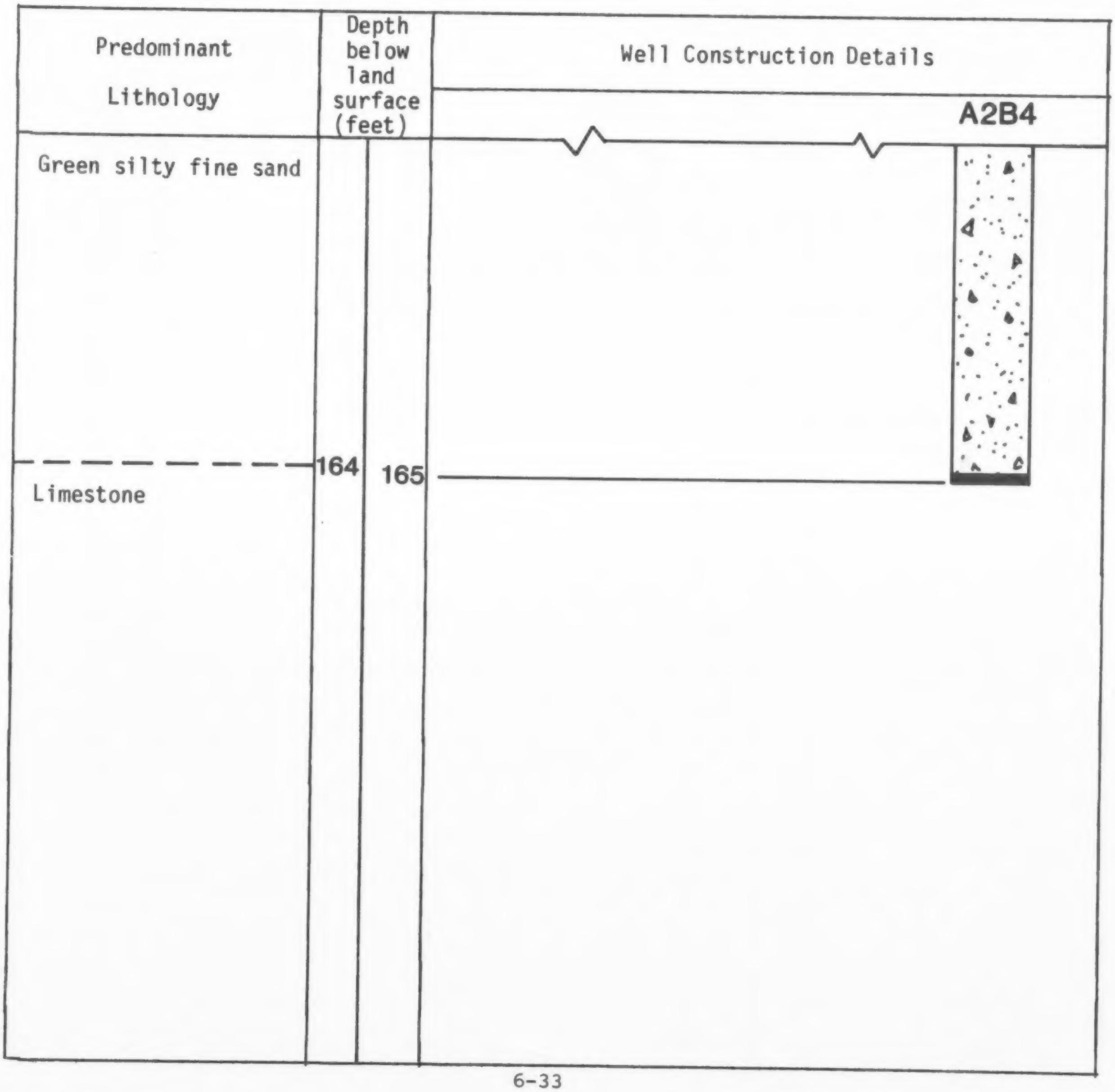
Well construction: The wells are constructed of schedule 40 PVC pipe and are finished at land surface in utility boxes. The wells are enclosed at land surface in steel pipes with locking caps.


Predominant Lithology
Depth below land surface (feet)
Well Construction Details
A2B1
A2B3
A2B4
Light brown fine sand
6
Silty fine sand
7.5
Gray fine sand with some occurrences of silt and shells
32
Interbedded gray silty clay, silt and silty fine sand
72
Greenish-gray fine to coarse sand and shells
110
see next page
4.7
9.7
12
25
30
37
85
90
2"
2"
2"

WELL CONSTRUCTION RECORD

Site ID:	A2B (cont'd)
Client:	EPA
Location:	Atlantic Beach, NC
Project No.:	172
Geologist:	T. Corwin, J. Fish

Well construction: The wells are constructed of schedule 40 PVC pipe and are finished at land surface in utility boxes. The wells are enclosed at land surface in steel pipes with locking caps.


Predominant Lithology
Depth below land surface (feet)
Well Construction Details
A2B4
Green silty fine sand
164
165
Limestone

WELL CONSTRUCTION RECORD

Site ID: A2C

Client: EPA

Location: Atlantic Beach, NC

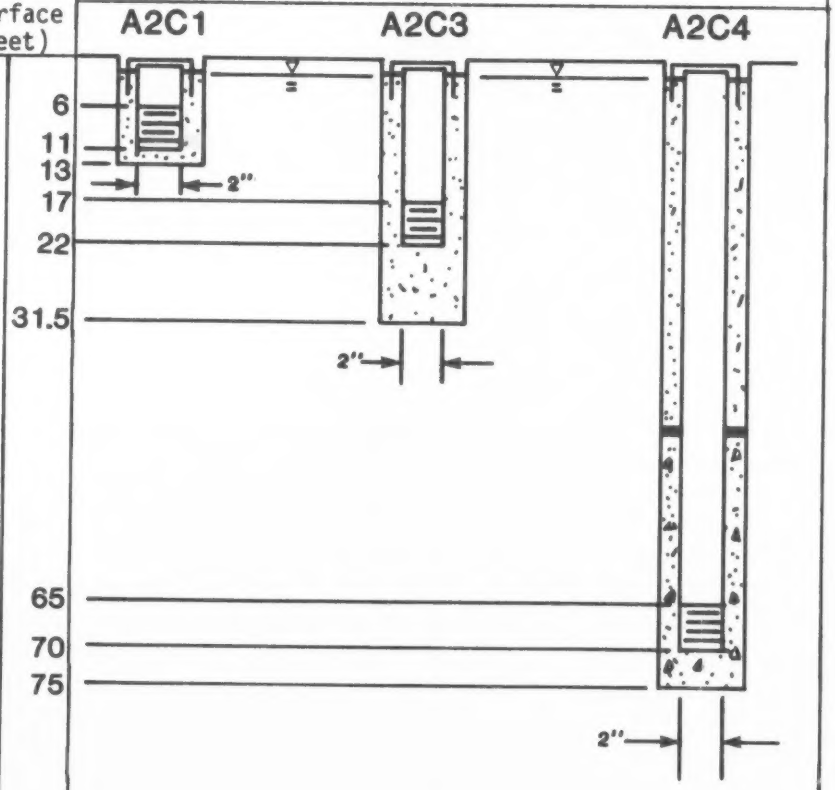
Project No.: 172

Geologist: T. Corwin

Well construction: The wells are constructed of schedule 40 PVC pipe and are finished at land surface in utility boxes. The wells are enclosed at land surface in steel pipes with locking caps.

Predominant Lithology	Depth below land surface (feet)
Tan to gray fine to medium sand	
	10
Gray fine sand	
	23
Gray clayey silt and silty fine sand	
	60
Gray fine to medium sand and shells	

Well Construction Details



WELL CONSTRUCTION RECORDS
FOR
PINE KNOLL SHORES

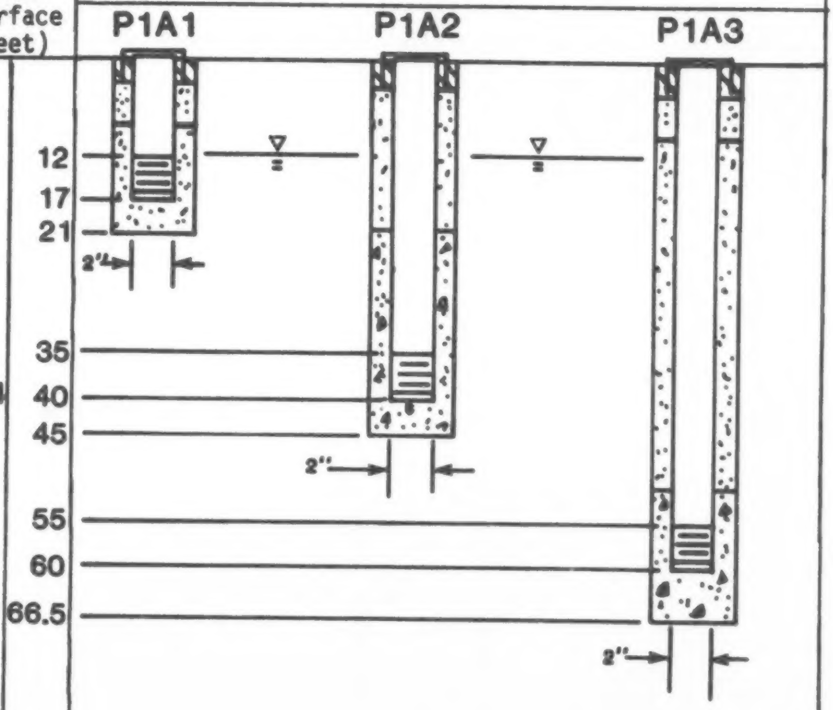
WELL CONSTRUCTION RECORD

Site ID: P1A
Client: EPA
Location: Pine Knoll Shores, NC
Project No.: 172
Geologist: J. Fish, T. Corwin

Well construction: The wells are constructed of schedule 40 PVC pipe and are finished about one foot above land surface. The wells are enclosed at land surface in steel pipes with locking caps.

Predominant Lithology	Depth below land surface (feet)
Tan fine to medium sand	12
Fine to medium gray sand with some shells	40.4
Gray fine sand	62
Gray clay with some fine sand	

Well Construction Details



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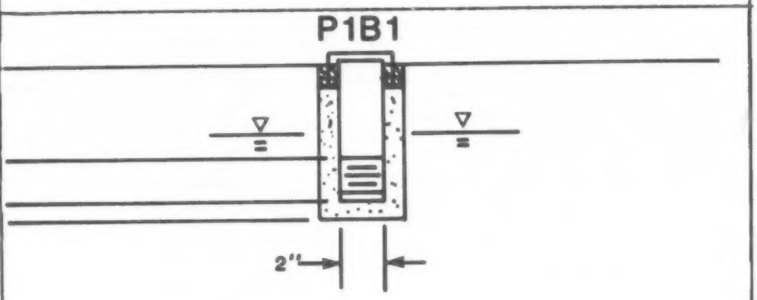
WELL CONSTRUCTION RECORD

Site ID: P1B
Client: EPA
Location: Pine Knoll Shores, NC
Project No.: 172
Geologist: J. Fish

Well construction: The well is constructed of schedule 40 PVC pipe and is finished about one foot above land surface. The well is enclosed at land surface in a steel pipe with a locking cap.

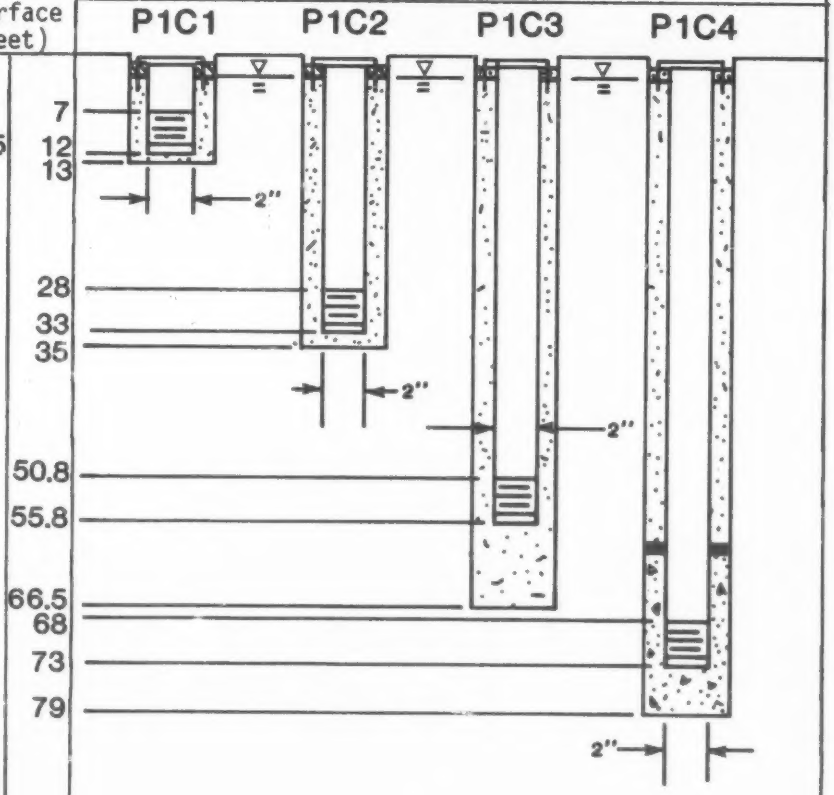
Predominant Lithology	Depth below land surface (feet)	Well Construction Details
Tan fine sand with some shells	11.6 16.6 19	

WELL CONSTRUCTION RECORD

Site ID: P1C	Well construction: The wells are constructed of schedule 40 PVC pipe and are finished at land surface in utility boxes. The wells are enclosed at land surface in steel pipes with locking caps.
Client: EPA	
Location: Pine Knoll Shores, NC	
Project No.: 172	
Geologist: J. Fish, T. Corwin	

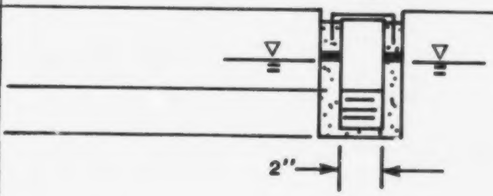
Predominant Lithology	Depth below land surface (feet)
Tan to brown fine sand	6.5
Gray to green fine sand with lenses of organic silt	11.5
Gray fine to medium sand with occurrences of shells	58
Interbedded layers of gray clay, silt and silty fine sand	68
Fine to medium sand and shells	73
Green silt and fine sand	

Well Construction Details



WELL CONSTRUCTION RECORD

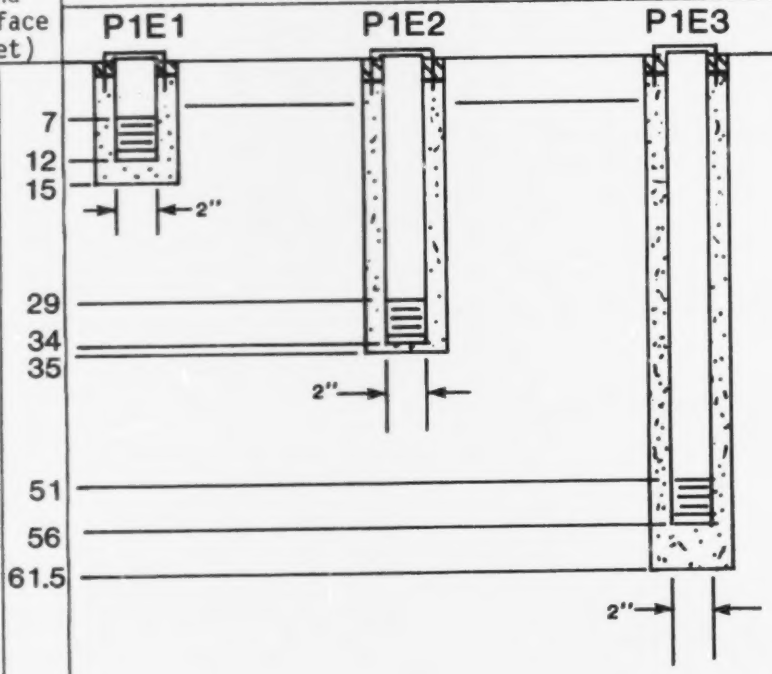
Site ID: P1D Client: EPA Location: Pine Knoll Shores, NC Project No.: 172 Geologist: J. Fish	Well construction: The well is constructed of schedule 40 PVC pipe and is finished at land surface in a utility box. The well is enclosed at land surface in a steel pipe with a locking cap.

Predominant Lithology	Depth below land surface (feet)		Well Construction Details
			P1D1
Dark brown fine sand			
Light brown fine sand with shells	6	10 15	

WELL CONSTRUCTION RECORD

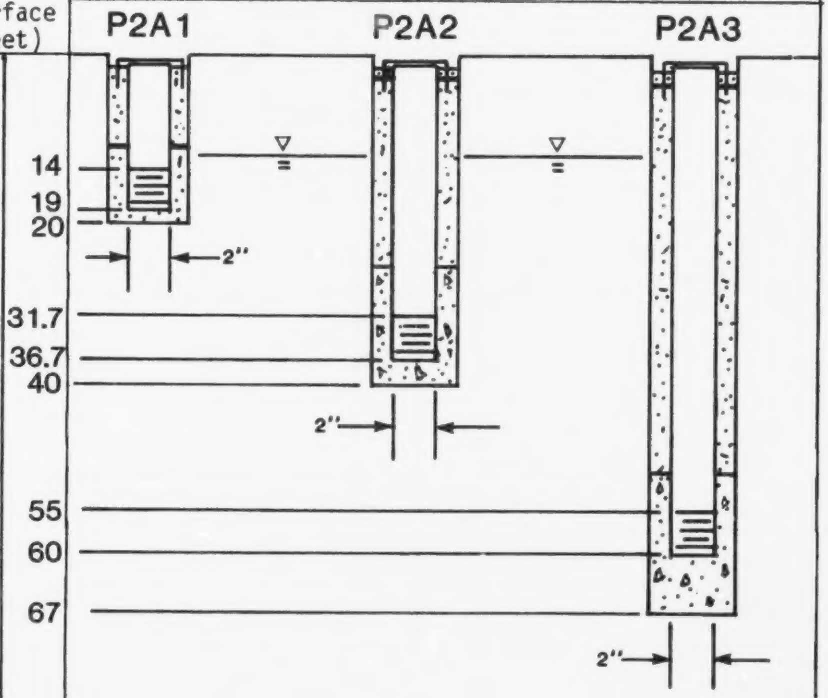
Site ID: P1E
Client: EPA
Location: Pine Knoll Shores, NC
Project No.: 172
Geologist: J. Fish, T. Corwin

Well construction: The wells are constructed of schedule 40 PVC pipe and are finished about one foot above land surface. The wells are enclosed at land surface in steel pipes with locking caps.

Predominant Lithology	Depth below land surface (feet)	Well Construction Details
Brown to tan fine sand	12	 P1E1 P1E2 P1E3 7 12 15 29 34 35 51 56 61.5 2" 2" 2"
Gray fine to medium sand with occurrences of shells	57	
Interbedded gray clay, clayey silt and silty sand		

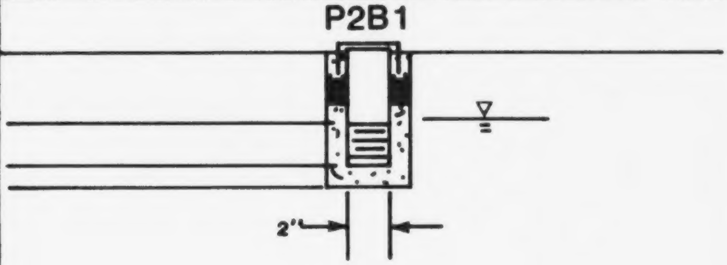
WELL CONSTRUCTION RECORD

Site ID:	P2A	Well construction: The wells are constructed of schedule 40 PVC pipe and are finished at land surface in utility boxes. The wells are enclosed at land surface in steel pipes with locking caps.
Client:	EPA	
Location:	Pine Knoll Shores, NC	
Project No.:	172	
Geologist:	T. Corwin, J. Fish	

Predominant Lithology	Depth below land surface (feet)	Well Construction Details
Tan to light brown fine to medium sand		
Gray fine sand with some shells	30	
Soft gray clayey to silty fine sand	61.5	

WELL CONSTRUCTION RECORD

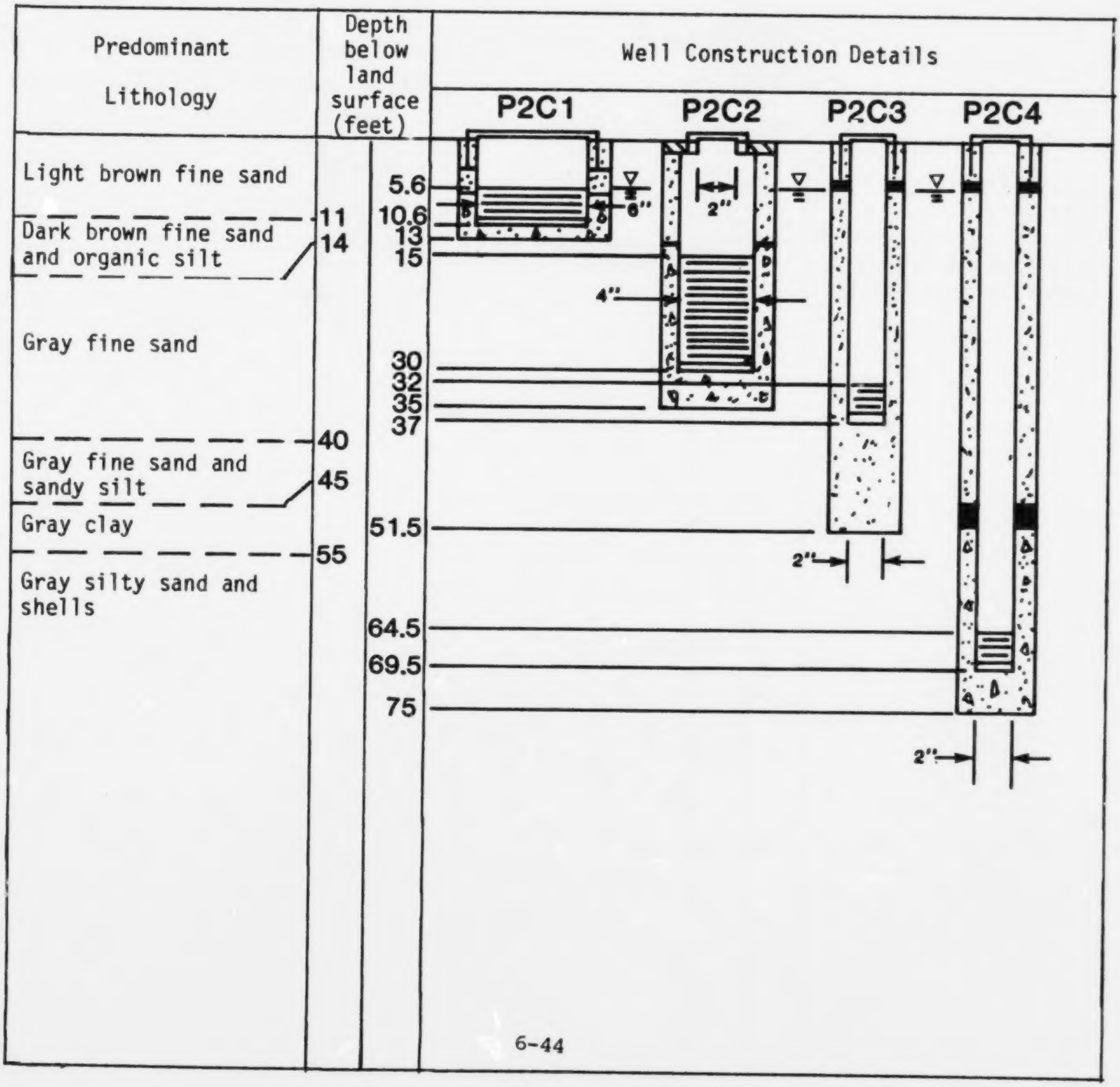
Site ID: P2B	Well construction: The well is constructed of schedule 40 PVC pipe and is finished about one foot above land surface. The well is enclosed at land surface in a steel pipe with a locking cap.
Client: EPA	
Location: Pine Knoll Shores, NC	
Project No.: 172	
Geologist: J. Fish	

Predominant Lithology	Depth below land surface (feet)		Well Construction Details
Tan to light brown fine sand		9	
Gray fine to medium sand with some shells	12	14 16.5	

WELL CONSTRUCTION RECORD

Site ID: P2C
Client: EPA
Location: Pine Knoll Shores, NC
Project No.: 172
Geologist: T. Corwin, J. Fish

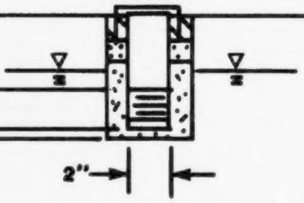
Well construction: The wells are constructed of schedule 40 PVC pipe and are finished about one foot above land surface. The wells are enclosed at land surface in steel pipes with locking caps.


Predominant Lithology
Depth below land surface (feet)
Well Construction Details
P2C1
P2C2
P2C3
P2C4
Light brown fine sand
11
Dark brown fine sand and organic silt
14
Gray fine sand
40
Gray fine sand and sandy silt
45
Gray clay
55
Gray silty sand and shells
5.6
10.6
13
15
30
32
35
37
51.5
64.5
69.5
75
6"
2"
4"
2"
2"

WELL CONSTRUCTION RECORD

Site ID: P2D
Client: EPA
Location: Pine Knoll Shores, NC
Project No.: 172
Geologist: T. Corwin

Well construction: The well is constructed of schedule 40 PVC pipe and is finished about one foot above land surface. The well is enclosed at land surface in a steel pipe with a locking cap.

Predominant Lithology	Depth below land surface (feet)		Well Construction Details
			P2D1
Light brown fine sand	7.5		
Light brown fine sand with some silt		9 14 15	

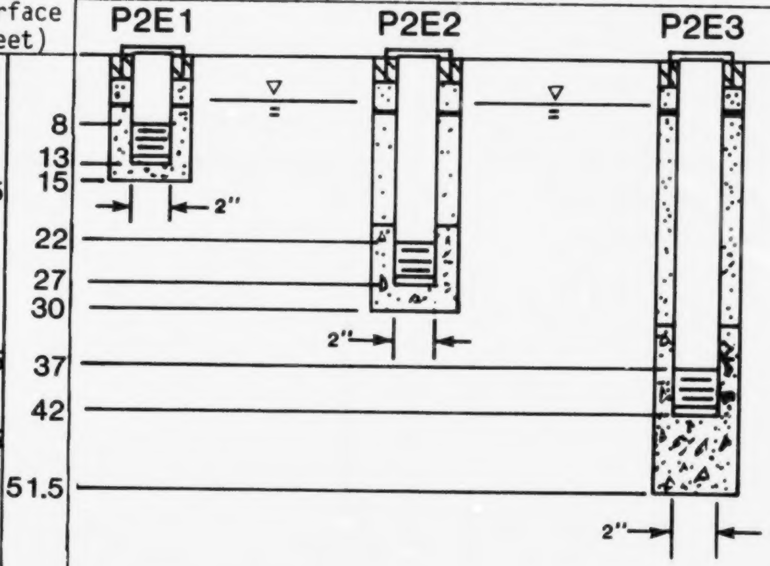
WELL CONSTRUCTION RECORD

Site ID: P2E
Client: EPA
Location: Pine Knoll Shores, NC
Project No.: 172
Geologist: T. Corwin

Well construction: The wells are constructed of schedule 40 PVC pipe and are finished about one foot above land surface. The wells are enclosed at land surface in steel pipes with locking caps.

Predominant Lithology	Depth below land surface (feet)
Silt (Fill material)	5.5
Brown peat and silt	6.5
Tan to light gray fine sand with some silt	16.5
Gray fine to medium sand with shells	36.5
Gray fine sand and silty fine sand	46.5
Soft gray clay	

Well Construction Details



WELL CONSTRUCTION RECORDS
FOR
SURF CITY

WELL CONSTRUCTION RECORD

Site ID: S1A

Client: EPA

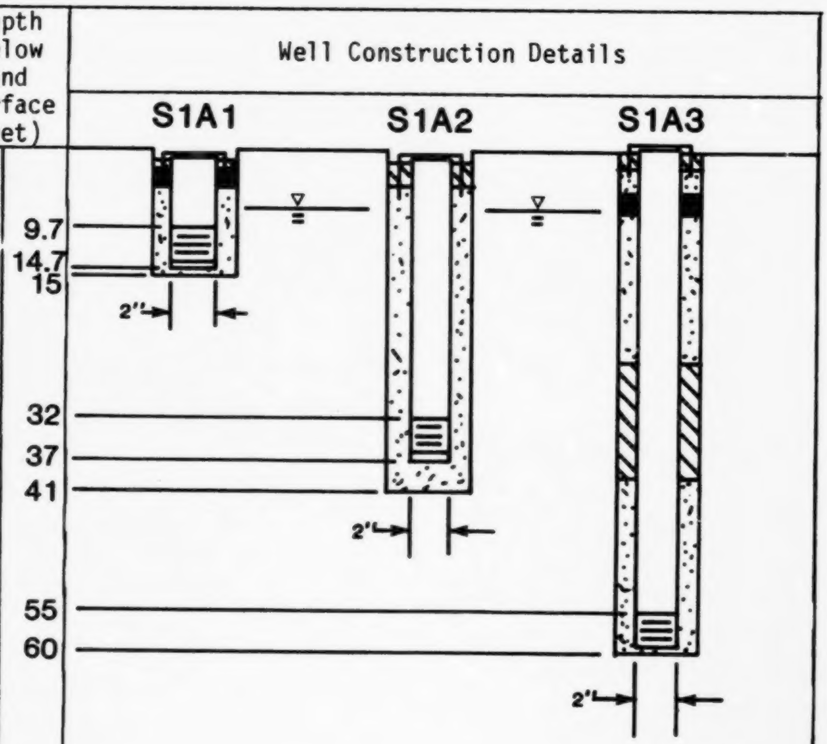
Location: Surf City, NC

Project No.: 172

Geologist: J. Fish, T. Corwin

Well construction: The wells are constructed of schedule 40 PVC pipe. Wells S1A1 and S1A2 are finished at land surface in utility boxes and well S1A3 is finished about one foot above land surface. The wells are enclosed at land surface in steel pipes with locking caps.

Predominant Lithology	Depth below land surface (feet)
Tan fine to medium sand	10
White and brown fine to coarse sand and shells	20
Tan fine to medium sand and shells	37
Gray clay	40.5
Gray limestone	50
Tan sandstone	



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WELL CONSTRUCTION RECORD

Site ID: S1B

Client: EPA

Location: Surf City, NC

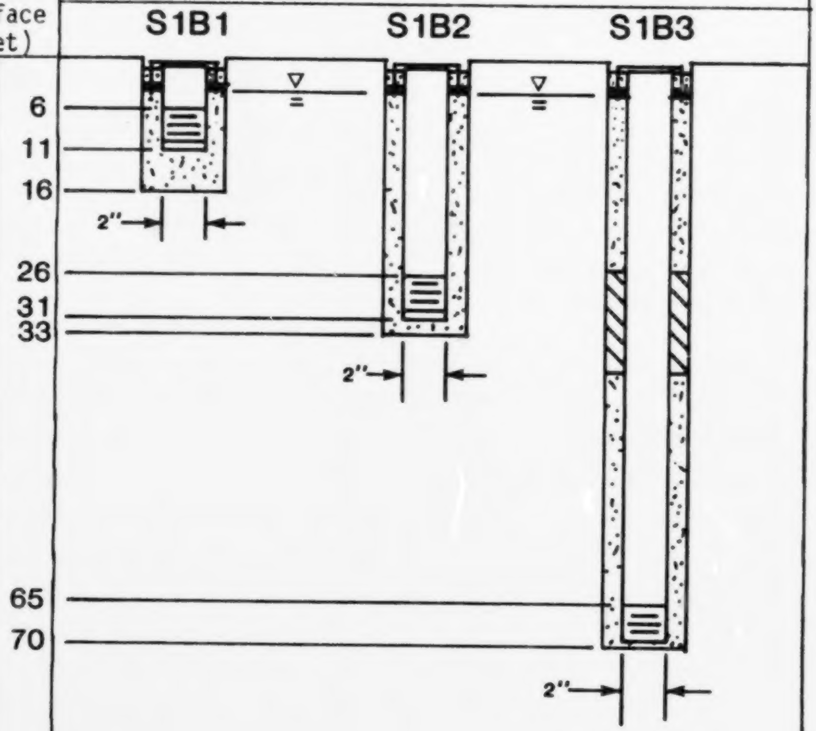
Project No.: 172

Geologist: J. Fish, T. Corwin

Well construction: The wells are constructed of schedule 40 PVC pipe and are finished at land surface in utility boxes. The wells are enclosed at land surface in steel pipes with locking caps.

Predominant Lithology	Depth below land surface (feet)
Brown fine to medium sand and shells	15
Brown to gray medium to coarse sand and shells	25
Gray fine to medium sand	33
Gray fine silty sand	36
Gray limestone	53
Tan sandstone	

Well Construction Details



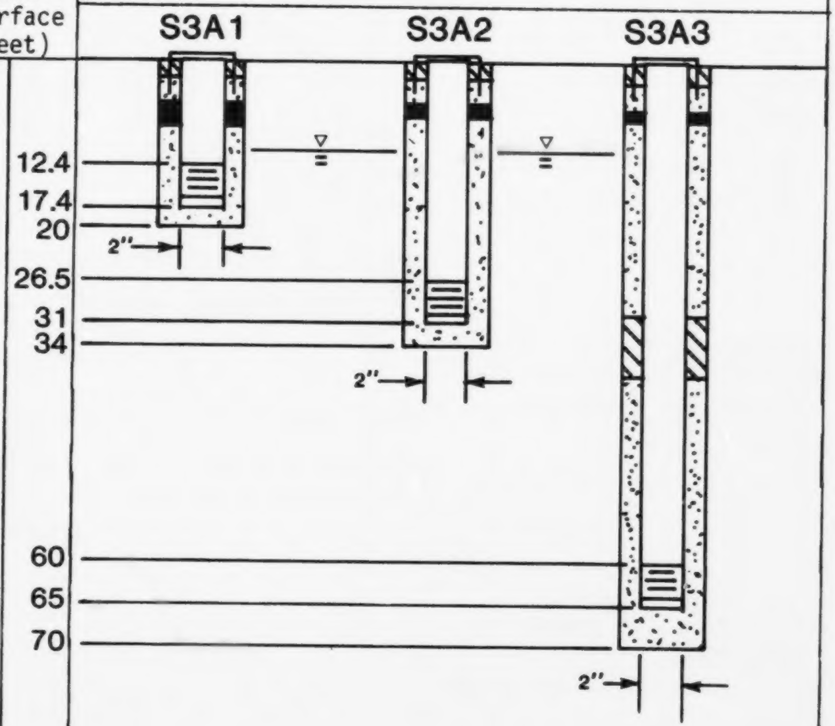
WELL CONSTRUCTION RECORD

Site ID: S3A
Client: EPA
Location: Surf City, NC
Project No.: 172
Geologist: J. Fish, T. Corwin

Well construction: The wells are constructed of schedule 40 PVC pipe and are finished about 0.5 feet above land surface. The wells are enclosed at land surface in steel pipes with locking caps.

Predominant Lithology	Depth below land surface (feet)
Tan to brown fine to medium sand and shells	10
Gray fine to coarse sand and shells	25
Tan medium to coarse sand and shells	34
Fine sandy silt	38
Gray limestone	56
Interbedded gray limestone, tan sandstone and very fine sand	

Well Construction Details



WELL CONSTRUCTION RECORD

Site ID: S3B

Client: EPA

Location: Surf City, NC

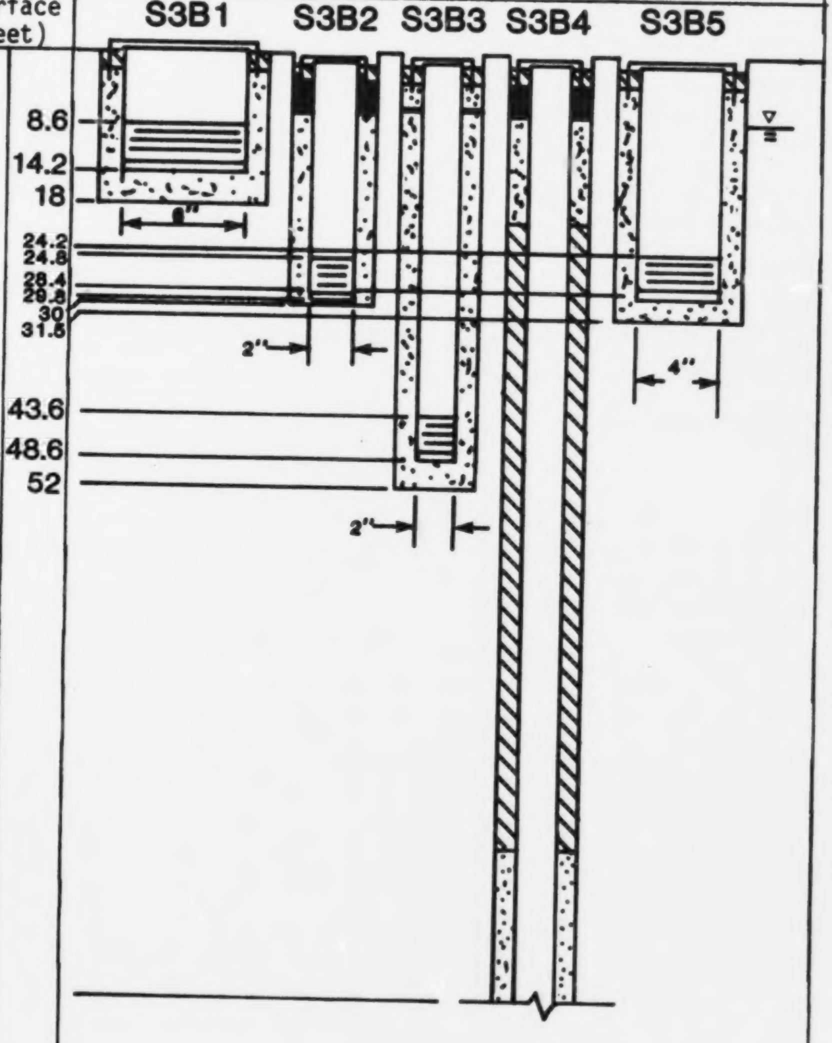
Project No.: 172

Geologist: J. Fish, T. Corwin

Well construction: The wells are constructed of schedule 40 PVC pipe. Well S3B1 is finished about 1.5 feet above land surface while wells S3B2, S3B3, S3B4 and S3B5 are finished at land surface in utility boxes. The wells are enclosed at land surface in steel pipes with locking caps.

Predominant Lithology	Depth below land surface (feet)
Tan fine to medium sand and shells	6
Gray fine to medium sand and shells	31
Silty clay	34
Light gray limestone	60
Interbedded gray limestone and green sandstone	75
Green sandstone	113
see next page	

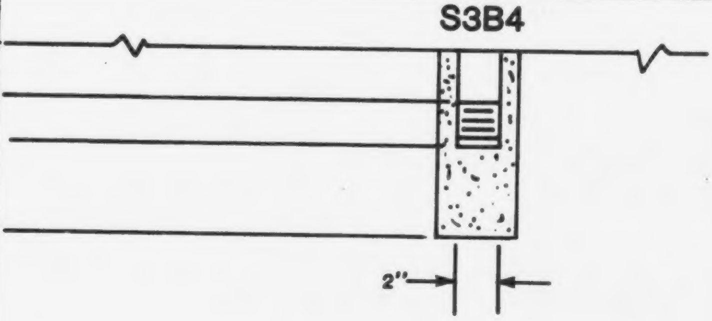
Well Construction Details



WELL CONSTRUCTION RECORD

Site ID: S3B (cont'd)
Client: EPA
Location: Surf City, NC
Project No.: 172
Geologist: J. Fish, T. Corwin

Well construction: The wells are constructed of schedule 40 PVC pipe. Well S3B1 is finished about 1.5 feet above land surface while wells S3B2, S3B3, S3B4 and S3B5 are finished at land surface in utility boxes. The wells are enclosed at land surface in steel pipes with locking caps.

Predominant Lithology	Depth below land surface (feet)	Well Construction Details
Gray limestone	119 124 135	

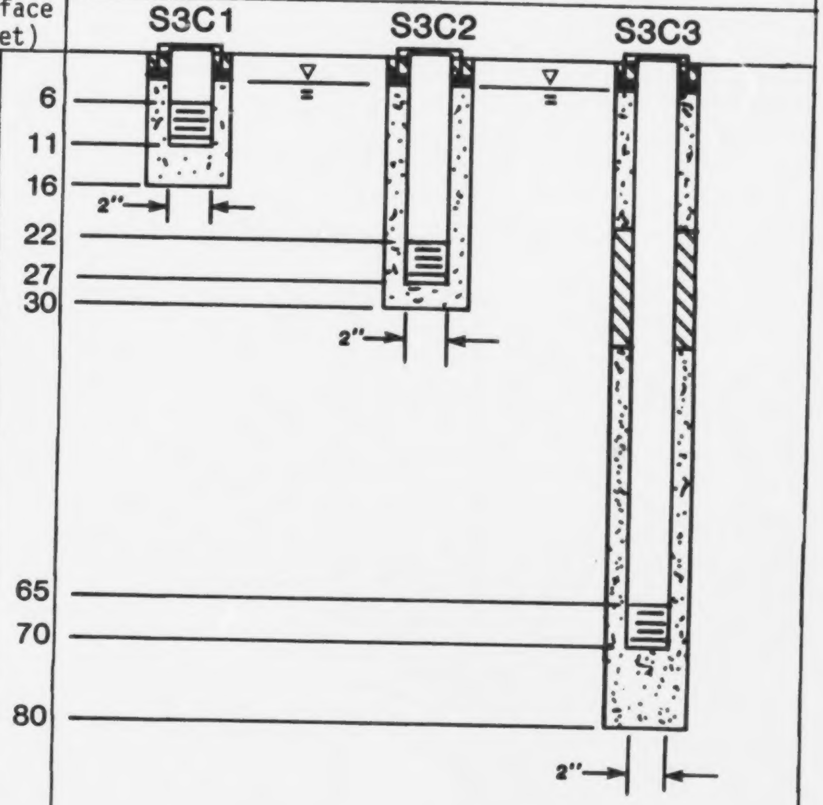
WELL CONSTRUCTION RECORD

Site ID: S3C
Client: EPA
Location: Surf City, NC
Project No.: 172
Geologist: J. Fish, T. Corwin

Well construction: The wells are constructed of schedule 40 PVC pipe and are finished about one foot above land surface. The wells are enclosed at land surface in steel pipes with locking caps.

Predominant Lithology	Depth below land surface (feet)
Black silt	
	6
Gray fine to medium sand and shells	
	27
Gray silty clay	
	30
Gray limestone	
	43
Tan sandstone	
	48
Interbedded sandstone and limestone	
	70
Green sand and sandstone	

Well Construction Details



APPENDIX B

LITHOLOGY SAMPLING RECORDS

Lithology sampling records have been completed for each monitoring well site in each study area. At some sites multiple wells were used to complete the lithology record for the site.

In the records that follow, the column headings have the following meaning:

Depth:	Depth in feet below land surface.
Sampler blows:	The number of blows required to drive a split-spoon sampler 18 inches into the ground. Testing is divided into three six-inch increments. The maximum number of blows used in this test per six-inch increment is 50. The depth the sampler was driven in the six-inch increment is recorded in parentheses if 50 blows were reached and further sampling for that interval is discontinued.
Percent Recovery:	The percentage of sample recovered in the split-spoon sampler.
Sample ID:	The identification number asigned to the sample.
Sample description:	A physical description of the material encountered as drilling progressed. A description of the material retrieved by sampling is described next to the sample ID number.

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LITHOLOGY SAMPLING RECORDS

FOR

KILL DEVIL HILLS

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LITHOLOGY SAMPLING RECORD

Page 1 of 3

Well ID:	K1A3	Date well drilled:	May 9, 1984
Client:	EPA	Borehole depth:	86.5 ft
Location:	Kill Devil Hills, NC	Drilling method:	Mud rotary
Project No.:	172	Sampling method:	Split spoon
Geologist:	J. Fish	Driller:	A-C Borings, Inc.

Depth (feet)	Sampler Blows	Percent Recovery	Sample ID	Sample Description
0	2/3/6	100	1	Tan to brown medium sand
5	1/1/2	65	2	Tan to brown medium sand
10	8/8/12	20	3	Tan to brown medium sand
15	11/12/16	35	4	Light brown fine to coarse sand with some shell fragments
20	19/25/26	70	5	Very dense light brown fine sand
25	16/27/28	0	6	No recovery

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LITHOLOGY SAMPLING RECORD

Depth (feet)	Sampler Blows	Percent Recovery	Sample ID	Sample Description
30	14/19/17	85	7	Gray to brown fine to medium sand
35	8/8/10	50	8	Gray to brown fine to medium sand
40	21/37/38	55	9	Very dense gray fine to medium sand
45	9/16/24	65	10	Dense gray fine sand
50	10/32/46	70	11	Gray fine sand
55	15/17/23	85	12	Dense gray fine sand
60	25/47/25	60	13	Very dense gray fine sand
65	15/26/30	70	14	Very dense gray fine sand

LITHOLOGY SAMPLING RECORD

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Depth (feet)	Sampler Blows	Percent Recovery	Sample ID	Sample Description
70	11/18/19	60	15	Dense gray fine sand
75	5/7/5	85	16	Gray fine sand with some clay
80	2/4/5	100	17	Loose gray fine sand with some silt
85	5/1/4	40	18	Soft gray silt and sand

LITHOLOGY SAMPLING RECORD

Well ID: K1B1	Date well drilled: April 26, 1984
Client: EPA	Borehole depth: 12.0 ft
Location: Kill Devil Hills, NC	Drilling method: Auger
Project No.: 172	Sampling method: Cuttings Examination
Geologist: T. Corwin	Driller: A-C Borings, Inc.

Depth (feet)	Sampler Blows	Percent Recovery	Sample ID	Sample Description
0				Brown fine to medium sand from 0 to 6 ft
5				
				Light gray fine sand from 6 to 12 ft
10				
12				

LITHOLOGY SAMPLING RECORD

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Well ID:	K1C2 (Replaced with K1C4)	Date well drilled:	May 1, 1984
Client:	EPA	Borehole depth:	41.5 ft
Location:	Kill Devil Hills, NC	Drilling method:	Mud rotary
Project No.:	172	Sampling method:	Split spoon
Geologist:	T. Corwin	Driller:	A-C Borings, Inc.

Depth (feet)	Sampler Blows	Percent Recovery	Sample ID	Sample Description
0	1/1/1	50	1	Very loose light brown fine sand
5	2/3/4	65	2	Loose light brown fine to medium sand
10	1/1/1	45	3	Very loose light brown to gray fine sand Peat encountered between 10.5 ft and 12 ft
15	16/19/32	70	4	Dense light gray fine sand
20	13/22/25	55	5	Light gray fine sand
25	13/34/48	85	6	Very dense light gray fine sand

LITHOLOGY SAMPLING RECORD

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Depth (feet)	Sampler Blows	Percent Recovery	Sample ID	Sample Description
30	14/27/39	65	7	Dense light gray fine to medium sand
35	17/26/40	70	8	Dense light gray fine sand with some shell fragments
40	12/17/30	55	9	Dense light gray fine to medium sand

LITHOLOGY SAMPLING RECORD

Well ID: K1C3 (Replaced with K1C5)	Date well drilled: May 2, 1984
Client: EPA	Borehole depth: 86.5 ft
Location: Kill Devil Hills, NC	Drilling method: Mud rotary
Project No.: 172	Sampling method: Split spoon
Geologist: T. Corwin	Driller: A-C Borings, Inc.

Depth (feet)	Sampler (Blows)	Percent Recovery	Sample ID	Sample Description
45	26/47/ 50(4")	100	10	Dense light gray fine to medium sand with some coarse sand and shell
50	22/39/ 50(5")	70	11	Dense light gray fine sand
55	16/28/50	100	12	Light gray coarse sand with shells near top of sample and light gray fine sand near bottom of sample
60	9/11/22	50	13	Dense light gray fine sand
65	10/14/19	55	14	Dense light gray silty fine sand
70	10/16/20	65	15	Firm light gray silty fine sand

LITHOLOGY SAMPLING RECORD

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Depth (feet)	Sampler Blows	Percent Recovery	Sample ID	Sample Description
75	8/11/13	90	16	Firm light gray silty fine sand
80	10/16/17	55	17	Dense gray silty fine sand with a trace of clay at bottom of sample
85	3/4/12	100	18	Firm dark gray clayey fine sand
				See log for well K1C2 for sampling from land surface to 40 ft

LITHOLOGY SAMPLING RECORD

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Well ID:	K1D1	Date well drilled:	April 27, 1984
Client:	EPA	Borehole depth:	13.0 ft
Location:	Kill Devil Hills, NC	Drilling method:	Auger
Project No.:	172	Sampling method:	Cuttings Examination
Geologist:	J. Fish	Driller:	A-C Borings, Inc.

Depth (feet)	Sampler Blows	Percent Recovery	Sample ID	Sample Description
0				
5				Light brown fine to medium sand from 0 to 13 ft
10				
13				

LITHOLOGY SAMPLING RECORD

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Well ID:	K1E3	Date well drilled:	April 27, 1984
Client:	EPA	Borehole depth:	96.5 ft
Location:	Kill Devil Hills, NC	Drilling method:	Mud rotary
Project No.:	172	Sampling method:	Split spoon
Geologist:	T. Corwin	Driller:	A-C Borings, Inc.

Depth (feet)	Sampler Blows	Percent Recovery	Sample ID	Sample Description
0	1/1/1	100	1	Organic silt
5	2/3/3	50	2	Gray fine sand
10	3/4/5	65	3	Loose gray fine sand
15	3/3/7	75	4	Dark gray clayey silt to 15.3 ft, then loose gray fine sand
20	3	100	5	Gray sandy silt to silty fine sand
25	9/8/7	55	6	Firm light gray fine sand with a trace of shell fragments

Depth (feet)	Sampler Blows	Percent Recovery	Sample ID	Sample Description
30	8/8/6	45	7	Firm light gray fine sand with a trace of shell fragments
35	1/5/7	75	8	Firm gray medium sand with some large shell fragments
40	5/10/11	45	9	Firm light gray medium sand with some shell fragments
45	15/25/29	35	10	Very dense light gray fine to medium sand with some shell fragments
50	16/27/32	100	11	Dense light gray fine to medium sand to 50.3 ft, then shell fragments with coarse sand to 50.8 ft, then dense light gray fine to medium sand
55	20/23/33	100	12	Dense gray medium sand with shell fragments to 55.8 ft, then dense gray fine sand
60	20/23/38	65	13	Very dense gray fine sand
65	9/11/15	55	14	Firm gray fine sand

LITHOLOGY SAMPLING RECORD

Depth (feet)	Sampler Blows	Percent Recovery	Sample ID	Sample Description
70	18/26/32	70	15	Very dense green to gray fine sand
75	1/1/1	100	16	Very soft gray silty fine sand
80	8/9/8	100	17	Gray silty fine sand to 81.3 ft, then stiff gray sandy silt
85	2/3/6	100	18	Loose gray silty fine sand
90	1/1/9	100	19	Soft gray sandy silt to 90.9 ft, then firm gray fine sand
95	26/32/35	90	20	Gray sandy silt to 95.4 ft, then very dense gray fine sand

LITHOLOGY SAMPLING RECORD

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Well ID:	K2A3	Date well drilled:	May 10, 1984
Client:	EPA	Borehole depth:	110 ft
Location:	Kill Devil Hills, NC	Drilling method:	Mud rotary
Project No.:	172	Sampling method:	Split spoon
Geologist:	J. Fish	Driller:	A-C Borings, Inc.

Depth (feet)	Sampler Blows	Percent Recovery	Sample ID	Sample Description
0	6/8/7	100	1	Firm tan fine to medium sand
5	3/6/8	70	2	Firm tan fine to medium sand
10	5/5/14	95	3	Firm light brown fine to coarse sand
15	8/22/41	35	4	Very dense light brown fine to coarse sand
20	32/47/ 50(5")	80	5	Very dense tan fine to coarse sand with shell fragments
25	27/30/30	75	6	Very dense tan fine sand

LITHOLOGY SAMPLING RECORD

Depth (feet)	Sampler Blows	Percent Recovery	Sample ID	Sample Description
30	17/24/34	70	7	Very dense tan fine sand
35	21/27/38	50	8	Very dense tan fine sand
40	22/33/39	70	9	Very dense tan fine to medium sand
45	22/31/ 50(6")	70	10	Very dense gray fine sand
50	20/31/42	60	11	Very dense gray fine sand
55	20/28/33	85	12	Very dense gray fine sand
60	2/6/18	100	13	Firm gray fine sand
65	18/32/ 50(5.5")	80	14	Very dense tan fine sand

Depth (feet)	Sampler Blows	Percent Recovery	Sample ID	Sample Description
70	39/50 (5")	90	15	Very dense tan fine sand with some clay
75	50(5")	100	16	Very dense tan fine sand with lenses of gray silty sand
80	50(4.5")	100	17	Very dense light gray fine to coarse sand
85	40/50 (4")	100	18	Very dense light gray fine to coarse sand
90	50(5")	100	19	Very dense white, tan and black medium to coarse sand
95				Fine to coarse sand from 92 ft to 97 ft
100				Alternating layers of fine sand and gray clay from 97 ft to 102 ft
105				Fine to coarse sand with shells from 102 ft to 110 ft
110				

LITHOLOGY SAMPLING RECORD Page 1 of 3

Well ID: K2B3	Date well drilled: May 13, 1984
Client: EPA	Borehole depth: 81.5 ft
Location: Kill Devil Hills, NC	Drilling method: Mud rotary
Project No.: 172	Sampling method: Split spoon
Geologist: T. Corwin	Driller: A-C Borings, Inc.

Depth (feet)	Sampler Blows	Percent Recovery	Sample ID	Sample Description
0				Light brown fine to medium sand from land surface to 7 ft
5				Gray to brown fine to medium sand from 7 ft to 10 ft
10	4/4/8	40	3	Firm light gray fine to medium sand
15	16/23/27	30	4	Dense light gray fine to medium sand
20	14/25/21	55	5	Dense light gray fine to medium sand
25	17/20/17	55	6	Dense light gray fine sand

LITHOLOGY SAMPLING RECORD

Depth (feet)	Sampler Blows	Percent Recovery	Sample ID	Sample Description
30	15/27/40	65	7	Very dense light gray medium to coarse sand
35	23/50 (4")	100	8	Very dense light gray fine sand
40	10/24/33	75	9	Very dense light gray fine to medium sand
45	20/43/ 50(3")	95	10	Very dense light gray fine sand with shell fragments
50	24/40/ 50(5")	80	11	Very dense light gray fine sand
55				
60	13/19/25	85	12	Dense gray medium sand
65				

LITHOLOGY SAMPLING RECORD

Depth (feet)	Sampler Blows	Percent Recovery	Sample ID	Sample Description
70	20/50 (4")	70	13	Very dense light gray medium sand with shell fragments
75				Clayey silt and silty sand from 77 ft to 80 ft
80	1/1/1	100	14	Interbedded clayey silts and silty fine sand

LITHOLOGY SAMPLING RECORD Page 1 of 2

Well ID:	K2C2	Date well drilled:	April 24, 1984
Client:	EPA	Borehole depth:	41.1 ft
Location:	Kill Devil Hills, NC	Drilling method:	Hollow stem auger
Project No.:	172	Sampling method:	Split spoon
Geologist:	T. Corwin	Driller:	A-C Borings, Inc.

Depth (feet)	Sampler Blows	Percent Recovery	Sample ID	Sample Description
0	1/2/5	75	1	Light brown medium sand
5	1/1/1	85	2	Very loose gray fine sand
10	2/1/2	65	3	Light gray fine to medium sand
15	2/5/9	75	4	Light gray fine to medium sand
20	8/26/38	85	5	Light gray fine to medium sand
25	20/30/42	100	6	Light gray fine to medium sand

Depth (feet)	Sampler Blows	Percent Recovery	Sample ID	Sample Description
30	9/14/41	100	7	Light gray fine to medium sand
35	24/50 (4.5")	85	8	Light gray fine to medium sand with some shell fragments
40	21/39/ 50(5")	75	9	Light gray medium to coarse sand with some shell fragments

LITHOLOGY SAMPLING RECORD

Well ID:	K2C3	Date well drilled:	April 24-25, 1984
Client:	EPA	Borehole depth:	91.5 ft
Location:	Kill Devil Hills, NC	Drilling method:	Mud rotary
Project No.:	172	Sampling method:	Split spoon
Geologist:	T. Corwin	Driller:	A-C Borings, Inc.

Depth (feet)	Sampler Blows	Percent Recovery	Sample ID	Sample Description
45	9/34/50	65	10	Light gray fine sand with shell fragments
50	22/34/50	70	11	Very dense light gray fine sand with a trace of shell fragments
55	31/50 (4")	35	12	Very dense light gray fine sand with a trace of shell fragments
60	8/9/14	65	13	Firm light gray fine sand
65	9/30/ 50(4.5")	60	14	Very dense light gray fine to medium sand
70	1/25/41	55	15	Very dense light gray to brown fine to medium sand

LITHOLOGY SAMPLING RECORD

Depth (feet)	Sampler Blows	Percent Recovery	Sample ID	Sample Description
75	37/50 (5")	0	16	No recovery
80	39/50 (3.5")	65	17	Very dense light gray fine to coarse sand with a trace of shell fragments
85	1/1/1	45	18	Gray silt with a trace of clay and some sand
90	6/5/6	55	19	Stiff gray sandy silt
				Green to gray coarse sand observed from cuttings for well K2C4 between 91 and 120 ft
				See log for well K2C2 for sampling from land surface to 40 ft

LITHOLOGY SAMPLING RECORD

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Well ID:	K2D3	Date well drilled:	April 28, 1984
Client:	EPA	Borehole depth:	85.0 ft
Location:	Kill Devil Hills, NC	Drilling method:	Mud rotary
Project No.:	172	Sampling method:	Split spoon
Geologist:	T. Corwin	Driller:	A-C Borings, Inc.

Depth (feet)	Sampler Blows	Percent Recovery	Sample ID	Sample Description
0				Light brown fine sand to 5 ft
5				
10				Light gray fine to medium sand from 5 to 19 ft
15				
20	Pushed sampler	100	1	Dark gray silty clay with fine sand
25				Light gray fine sand

LITHOLOGY SAMPLING RECORD

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Depth (feet)	Sampler Blows	Percent Recovery	Sample ID	Sample Description
30				
35				Light gray fine sand
40				Light gray fine to medium sand
45				
50				Gray fine to coarse sand with shells
55				
60				Gray fine to medium sand with shells
65				

LITHOLOGY SAMPLING RECORD

Depth (feet)	Sampler Blows	Percent Recovery	Sample ID	Sample Description
70				Gray medium sand with shells
75				
80				
				Gray medium sand with shells
				Gray silt with some clay from 81 to 85 ft
85				

LITHOLOGY SAMPLING RECORD

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Well ID:	K2E3	Date well drilled:	April 26, 1984
Client:	EPA	Borehole depth:	86.5 ft
Location:	Kill Devil Hills, NC	Drilling method:	Mud rotary
Project No.:	172	Sampling method:	Split spoon
Geologist:	J. Fish	Driller:	A-C Borings, Inc.

Depth (feet)	Sampler Blows	Percent Recovery	Sample ID	Sample Description
0	3/3/3	65	1	Brown fine to medium sand with thin lenses of peat
5	3/2/2	50	2	Brown to gray fine to medium sand
10	6/6/3	100	3	Gray fine sand
15	2/1/1	20	4	Gray fine sand with some silt
20	9/9/10	65	5	Gray fine sand with a trace of silt
25	4/7/9	45	6	Gray fine to medium sand

Depth (feet)	Sampler Blows	Percent Recovery	Sample ID	Sample Description
30	1/8/7	85	7	Gray fine sand with shell fragments
35	8/7/9	35	8	Gray fine sand
40	2/4/9	40	9	Gray fine sand
45	1/19/32	65	10	Gray fine sand
50	14/20/16	10	11	Gray medium to coarse sand with shell fragments
55	4/5/5	100	12	Dark brown organic silt to 56.2 ft,. then brown fine sand
60	9/21/43	85	13	Brown fine sand to silty fine sand
65	23/50 (6")	65	14	Very dense gray fine sand

LITHOLOGY SAMPLING RECORD

Depth (feet)	Sampler Blows	Percent Recovery	Sample ID	Sample Description
70	12/50 (5")	65	15	Very dense light gray fine sand
75	27/44/ 50(4")	60	16	Very dense light gray fine sand
80	23/16/9	35	17	Light gray fine sand Silty clay at 81 ft
85	3/4/8	100	18	Firm blue-gray clay

LITHOLOGY SAMPLING RECORD

Well ID:	K3A3 (Replaced with K3A3B)	Date well drilled:	April 11, 1984
Client:	EPA	Borehole depth:	56.5 ft
Location:	Kill Devil Hills, NC	Drilling method:	Hollow stem auger
Project No.:	172	Sampling method:	Split spoon
Geologist:	J. Fish	Driller:	A-C Borings, Inc.

Depth (feet)	Sampler Blows	Percent Recovery	Sample ID	Sample Description
0	2/2/3	45	1	Light brown medium sand
5	7/7/7	60	2	Light brown fine to medium sand with shell fragments
10	2/3/6	80	3	Light brown fine to coarse sand with shell fragments
15	11/18/36	50	4	Light brown fine to medium sand with shell fragments
20	20/29/33	50	5	Light brown fine to medium sand with shell fragments
25	22/28/36	25	6	Gray to brown fine sand with shell fragments

LITHOLOGY SAMPLING RECORD Page 2 of 2

Depth (feet)	Sampler Blows	Percent Recovery	Sample ID	Sample Description
30	22/40/ 50(2.5")	50	7	Gray fine sand with shell fragments
35	40/50 (4.5")	50	8	Gray fine sand with shell fragments and a trace of silt
40	22/46/ 50(3")	0	9	No recovery
45	14/21/4	35	10	Gray fine sand with a trace of silt
50	6/14/21	90	11	Gray fine sand with a trace of silt
55	1/7/20	60	12	Gray fine sand with a trace of silt

LITHOLOGY SAMPLING RECORD

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Well ID:	K3A3B	Date well drilled:	April 30, 1984
Client:	EPA	Borehole depth:	106.5 ft
Location:	Kill Devil Hills, NC	Drilling method:	Mud rotary
Project No.:	172	Sampling method:	Split spoon
Geologist:	T. Corwin	Driller:	A-C Borings, Inc.

Depth (feet)	Sampler Blows	Percent Recovery	Sample ID	Sample Description
60	26/40/ 50(5")	55	13	Very dense light gray fine sand
65	29/50 (5")	75	14	Very dense light gray fine sand
70	50(6")	100	15	Very dense light gray medium sand
75	20/50 (5.5")	60	16	Very dense light gray medium to coarse sand
80	29/50 (5")	80	17	Very dense light gray medium to coarse sand
85	17/32/48	55	18	Very dense light gray medium to coarse sand

LITHOLOGY SAMPLING RECORD

Depth (feet)	Sampler Blows	Percent Recovery	Sample ID	Sample Description
90	11/46/ 50(4")	55	19	Very dense light gray fine sand
95	39/50 (3")	80	20	Very dense light gray medium to coarse sand
100	3/7/11	95	21	Silty fine sand to 100.5 ft, then clayey silt to 101.0 ft, then silt
105	12/10/10	100	22	Silty sand
				See log for well K3A3 for sampling from land surface to 55 ft

LITHOLOGY SAMPLING RECORD

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Well ID:	K3B1	Date well drilled:	April 14, 1984
Client:	EPA	Borehole depth:	9.0 ft
Location:	Kill Devil Hills, NC	Drilling method:	Auger
Project No.:	172	Sampling method:	Cuttings Examination
Geologist:	J. Fish	Driller:	A-C Borings, Inc.

Depth (feet)	Sampler Blows	Percent Recovery	Sample ID	Sample Description
0				Light brown fine to medium sand from 0 to 3 ft
5				Gray fine to medium sand from 3 to 9 ft
9				

LITHOLOGY SAMPLING RECORD Page 1 of 1

Well ID: K3C1	Date well drilled: April 14, 1984
Client: EPA	Borehole depth: 9.0 ft
Location: Kill Devil Hills, NC	Drilling method: Auger
Project No.: 172	Sampling method: Cuttings Examination
Geologist: J. Fish	Driller: A-C Borings, Inc.

Depth (feet)	Sampler Blows	Percent Recovery	Sample ID	Sample Description
0				
5				Light brown fine to medium sand from 0 to 9 ft
9				

LITHOLOGY SAMPLING RECORD

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Well ID:	K3D3 (Replaced with K3D3B)	Date well drilled:	April 17, 1984
Client:	EPA	Borehole depth:	61.5 ft
Location:	Kill Devil Hills, NC	Drilling method:	Mud rotary
Project No.:	172	Sampling method:	Split spoon
Geologist:	T. Corwin	Driller:	A-C Borings, Inc.

Depth (feet)	Sampler Blows	Percent Recovery	Sample ID	Sample Description
0				Light brown fine to medium sand at surface
5	2/2/3	100	2	Light brown fine to medium sand
10	5/5/6	15	3	Light brown fine to medium sand
15	1/2/2	60	4	Light brown fine to medium sand to 15.9 ft, then sandy organic silt
				Gray fine sand at 18 ft
20	8/15/24	60	5	Gray fine sand
25	15/16/22	55	6	Gray fine sand

LITHOLOGY SAMPLING RECORD

Depth (feet)	Sampler Blows	Percent Recovery	Sample ID	Sample Description
30	16/19/14	30	7	Gray fine to medium sand with a trace of shell fragments
35	15/19/14	50	8	Gray fine to medium sand
40	16/26/35	60	9	Gray fine sand
45	20/32/41	55	10	Gray fine sand
50	17/50 (5.5")	30	11	Gray fine sand with some silt
55	34/50 (5")	50	12	Gray fine sand
60	17/43/50	Not Recorded	13	Gray fine sand with a trace of shell fragments

LITHOLOGY SAMPLING RECORD

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Well ID:	K3D3B	Date well drilled:	April 18, 1984
Client:	EPA	Borehole depth:	86.5 ft
Location:	Kill Devil Hills, NC	Drilling method:	Mud rotary
Project No.:	172	Sampling method:	Split spoon
Geologist:	T. Corwin	Driller:	A-C Borings, Inc.

Depth (feet)	Sampler Blows	Percent Recovery	Sample ID	Sample Description
65	16/23/15	15	14	Gray fine to medium sand with a trace of shell fragments
70	19/43/ 50(5")	65	15	Gray to tan medium sand
75	50(5.5")	20	16	Gray to tan medium sand with shell fragments
80	29/17/18	0	17	No recovery
				Clayey silt at 80.5 ft
85	3/4/5	Not recorded	18	Gray fine sandy silt
				See log for well K3D3 for sampling from land surface to 60 ft

LITHOLOGY SAMPLING RECORD

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Well ID:	K3E1	Date well drilled:	April 14, 1984
Client:	EPA	Borehole depth:	10.0 ft
Location:	Kill Devil Hills, NC	Drilling method:	Auger
Project No.:	172	Sampling method:	Cuttings Examination
Geologist:	J. Fish	Driller:	A-C Borings, Inc.

Depth (feet)	Sampler Blows	Percent Recovery	Sample ID	Sample Description
0				Brown fine to medium sand from 0 to 6.5 ft
5				
				Gray fine to medium sand from 6.5 to 10 ft
10				

LITHOLOGY SAMPLING RECORD

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Well ID:	K3F1	Date well drilled:	April 14, 1984
Client:	EPA	Borehole depth:	12.0 ft
Location:	Kill Devil Hills, NC	Drilling method:	Auger
Project No.:	172	Sampling method:	Cuttings Examination
Geologist:	J. Fish	Driller:	A-C Borings, Inc.

Depth (feet)	Sampler Blows	Percent Recovery	Sample ID	Sample Description
0				Light brown fine to medium sand from 0 to 12 ft
5				
10				
12				

LITHOLOGY SAMPLING RECORD

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Well ID:	K3G2	Date well drilled:	April 12, 1984
Client:	EPA	Borehole depth:	41.5 ft
Location:	Kill Devil Hills, NC	Drilling method:	Hollow stem auger
Project No.:	172	Sampling method:	Split spoon
Geologist:	T. Corwin	Driller:	A-C Borings, Inc.

Depth (feet)	Sampler Blows	Percent Recovery	Sample ID	Sample Description
0	3/3/4	40	1	Light brown fine sand
5	1/2/4	50	2	Light brown fine sand
10	1/2/6	40	3	Light gray fine to medium sand
15	7/11/16	45	4	Light gray fine sand
20	15/20/24	45	5	Light gray fine sand
25	7/14/21	50	6	Light gray fine sand with shell fragments

LITHOLOGY SAMPLING RECORD

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Depth (feet)	Sampler Blows	Percent Recovery	Sample ID	Sample Description
30	9/12/36	50	7	Light gray fine sand with shell fragments
35	11/14/24	70	8	Light gray fine sand with shell fragments
40	9/14/28	45	9	Light gray fine sand with shell fragments

LITHOLOGY SAMPLING RECORD

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Well ID:	K3G3	Date well drilled:	April 13, 1984
Client:	EPA	Borehole depth:	87.0 ft
Location:	Kill Devil Hills, NC	Drilling method:	Mud rotary
Project No.:	172	Sampling method:	Split spoon
Geologist:	J. Fish	Driller:	A-C Borings, Inc.

Depth (feet)	Sampler Blows	Percent Recovery	Sample ID	Sample Description
45	27/50 (5.5")	0	10	No recovery
50	13/30/40	60	11	Light gray fine sand
55	6/12/24	40	12	Gray and brown fine sand
60	10/37/ 50(5")	60	13	Light brown fine to medium sand
65	25/50 (6")	75	14	Gray fine to medium sand with clayey sand lenses
70	6/20/30	65	15	Gray fine sand with silty sand lenses

LITHOLOGY SAMPLING RECORD

Depth (feet)	Sampler Blows	Percent Recovery	Sample ID	Sample Description
75	8/13/14	20	16	Gray fine sand
80	5/6/8	30	17	Gray silty fine sand with a trace of clay
85	7/7/8	75	18	Gray clayey silt
				See log for well K3G2 for sampling from land surface to 40 ft

LITHOLOGY SAMPLING RECORDS

FOR

ATLANTIC BEACH

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LITHOLOGY SAMPLING RECORD

Well ID: A1A3	Date well drilled: June 20, 1984
Client: EPA	Borehole depth: 50.0 ft
Location: Atlantic Beach, NC	Drilling method: Mud rotary
Project No.: 172	Sampling method: Split spoon
Geologist: T. Corwin	Driller: A-C Borings, Inc.

Depth (feet)	Sampler Blows	Percent Recovery	Sample ID	Sample Description
0				
				Tan fine to medium sand from 0 to 9 ft
5				
10				
				Gray fine to medium sand from 9 to 20 ft
15				
20				
25				

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LITHOLOGY SAMPLING RECORD

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Depth (feet)	Sampler Blows	Percent Recovery	Sample ID	Sample Description
30				
35				Gray fine to medium sand with shells from 20 to 39 ft
				Silt from 39 to 40 ft
40	Pushed sampler	100	1	Gray fine to medium sand with shells
45				
				Soft gray clay from 46 to 50 ft
50				

LITHOLOGY SAMPLING RECORD

Page 1 of 2

Well ID:	A1B3	Date well drilled:	June 15, 1984
Client:	EPA	Borehole depth:	42.0 ft
Location:	Atlantic Beach, NC	Drilling method:	Mud rotary
Project No.:	172	Sampling method:	Split spoon
Geologist:	J. Fish, T. Corwin	Driller:	A-C Borings, Inc.

Depth (feet)	Sampler Blows	Percent Recovery	Sample ID	Sample Description
0				
5				Tan fine sand with a trace of shells from 0 to 12 ft
10				
15				
20				Gray silty fine sand from 12 to 24 ft
25				

LITHOLOGY SAMPLING RECORD

Depth (feet)	Sampler Blows	Percent Recovery	Sample ID	Sample Description
30				Tan to gray fine sand from 24 to 36 ft
35				Gray silty clay from 36 to 40 ft
40	Pushed sampler	30	1	Brown clay and shells from 40 to 40.5 ft, then gray silty fine sand
42				

LITHOLOGY SAMPLING RECORD

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Well ID:	A1C3	Date well drilled:	June 19, 1984
Client:	EPA	Borehole depth:	37.0 ft
Location:	Atlantic Beach, NC	Drilling method:	Mud rotary
Project No.:	172	Sampling method:	Cuttings examination
Geologist:	T. Corwin	Driller:	A-C Borings, Inc.

Depth (feet)	Sampler Blows	Percent Recovery	Sample ID	Sample Description
0				
5				Tan fine to medium sand and shells from 0 to 12 ft
10				
15				Interbedded layers of fine sand and silty fine sand with some shells from 12 to 24 ft
20				
25				Gray fine sand and shells from 24 to 32 ft

LITHOLOGY SAMPLING RECORD

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Depth (feet)	Sampler Blows	Percent Recovery	Sample ID	Sample Description
30				
35				Gray silty fine sand from 32 to 37 ft
37				

LITHOLOGY SAMPLING RECORD Page 1 of 2

Well ID:	A1D2	Date well drilled:	June 14, 1984
Client:	EPA	Borehole depth:	52.0 ft
Location:	Atlantic Beach, NC	Drilling method:	Mud rotary
Project No.:	172	Sampling method:	Split spoon
Geologist:	J. Fish	Driller:	A-C Borings, Inc.

Depth (feet)	Sampler Blows	Percent Recovery	Sample ID	Sample Description
0				Fine sand and gravel (probably fill) from 0 to 7 ft
5				
10				
				Gray fine sand from 7 to 18 ft
15				
20				
25				

LITHOLOGY SAMPLING RECORD

Depth (feet)	Sampler Blows	Percent Recovery	Sample ID	Sample Description
30				
35				Gray fine sand with some shells from 18 to 49 ft
40				
45				
50	Pushed sampler	0	1	No recovery. Wall of sampler has a gray clay. Clay starts at 49 ft

LITHOLOGY SAMPLING RECORD

Page 1 of 2

Well ID:	A1D3	Date well drilled:	June 13, 1984
Client:	EPA	Borehole depth:	110.0 ft
Location:	Atlantic Beach, NC	Drilling method:	Mud rotary
Project No.:	172	Sampling method:	Cuttings examination
Geologist:	J. Fish	Driller:	A-C Borings, Inc.

Depth (feet)	Sampler Blows	Percent Recovery	Sample ID	Sample Description
50				
60				Gray fine sand with a trace of shells from 52 to 70 ft
70				
80				Tan fine sand and shells from 70 to 86 ft
90				Tan fine to coarse sand and shells from 86 to 96 ft
100				Very hard fine to coarse sand and shells from 96 to 99 ft
110				Hard fine to coarse sand and shells from 99 to 110 ft

LITHOLOGY SAMPLING RECORD

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Depth (feet)	Sampler Blows	Percent Recovery	Sample ID	Sample Description
				See log for well A1D2 for sampling from land surface to 50 ft

LITHOLOGY SAMPLING RECORD

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Well ID:	A2A1	Date well drilled:	June 1, 1984
Client:	EPA	Borehole depth:	15.0 ft
Location:	Atlantic Beach, NC	Drilling method:	Auger
Project No.:	172	Sampling method:	Cuttings and Split spoon
Geologist:	T. Corwin	Driller:	A-C Borings, Inc.

Depth (feet)	Sampler Blows	Percent Recovery	Sample ID	Sample Description
0	Sampled cuttings		1	Brown to tan fine sand
5	3/5/6	65	2	Tan to gray fine sand

LITHOLOGY SAMPLING RECORD

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Well ID:	A2A3	Date well drilled:	June 1, 1984
Client:	EPA	Borehole depth:	41.5 ft
Location:	Atlantic Beach, NC	Drilling method:	Mud rotary
Project No.:	172	Sampling method:	Split spoon
Geologist:	J. Fish	Driller:	A-C Borings, Inc.

Depth (feet)	Sampler Blows	Percent Recovery	Sample ID	Sample Description
10	9/21/17	40	3	Tan fine to coarse sand with shells from 10.0 to 10.5 ft, then tan fine sand from 10.5 to 11.5 ft Silty fine sand starts at 14 ft
15	1/3/9	100	4	Gray fine sand and silty sand with shells
20	18/40/ 50(5")	75	5	Very dense gray fine sand
25	14/18/27	55	6	Dense gray fine sand with some shells
30	20/38/33	30	7	Very dense gray fine sand with some shells Clay starts at 32.5 ft
35	1/1/2	90	8	Soft gray clay with a trace of silt and sand

LITHOLOGY SAMPLING RECORD

Depth (feet)	Sampler Blows	Percent Recovery	Sample ID	Sample Description
40	6/2/3	35	9	Loose gray fine sand from 40.0 to 40.5 ft. Probably gray clay from 40.5 to 41.5 ft

LITHOLOGY SAMPLING RECORD

Page 1 of 1

Well ID: A2A4	Date well drilled: June 14, 1984
Client: EPA	Borehole depth: 70.0 ft
Location: Atlantic Beach, NC	Drilling method: Mud rotary
Project No.: 172	Sampling method: Cuttings examination
Geologist: J. Fish	Driller: A-C Borings, Inc.

Depth (feet)	Sampler Blows	Percent Recovery	Sample ID	Sample Description
40				Gray clay from 41 to 58 ft
50				
				Gray clay with shells from 53 to 58 ft
60				
70				Fine sand and shells from 58 to 70 ft
				See well logs for wells A2A1 and A2A3 for sampling from land surface to 40 ft

LITHOLOGY SAMPLING RECORD

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Well ID:	A2B1	Date well drilled:	June 1, 1984
Client:	EPA	Borehole depth:	12.0 ft
Location:	Atlantic Beach, NC	Drilling method:	Auger
Project No.:	172	Sampling method:	Split spoon
Geologist:	J. Fish	Driller:	A-C Borings, Inc.

Depth (feet)	Sampler Blows	Percent Recovery	Sample ID	Sample Description
0				Light brown fine sand
5	2/4/5	100	2	Light brown fine sand from 5.0 to 6.0 ft, then silty fine sand from 6.0 to 6.5 ft
				Silty fine sand ends at 7.5 ft

LITHOLOGY SAMPLING RECORD

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Well ID:	A2B3	Date well drilled:	June 1, 1984
Client:	EPA	Borehole depth:	37.0 ft
Location:	Atlantic Beach, NC	Drilling method:	Mud rotary
Project No.:	172	Sampling method:	Split spoon
Geologist:	J. Fish	Driller:	A-C Borings, Inc.

Depth (feet)	Sampler Blows	Percent Recovery	Sample ID	Sample Description
10	7/11/9	45	3	Gray fine sand with a trace of shells
15	2/1/1	90	4	Very loose gray fine sand with some silt
20	19/42/ 50(5")	55	5	Very dense gray fine sand
25	13/22/35	70	6	Very dense gray fine sand with shells
30	10/16/11	35	7	Firm gray fine sand with shells Clay starts at 32 ft
35	2/3/3	55	8	Firm gray silty clay with a trace of shells

LITHOLOGY SAMPLING RECORD

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Well ID:	A2B4	Date well drilled:	May 31, 1984
Client:	EPA	Borehole depth:	165.0 ft
Location:	Atlantic Beach, NC	Drilling method:	Mud rotary
Project No.:	172	Sampling method:	Split spoon
Geologist:	T. Corwin	Driller:	A-C Borings, Inc.

Depth (feet)	Sampler Blows	Percent Recovery	Sample ID	Sample Description
40				
50				Interbedded gray silty clay, silt and silty fine sand from 36.5 to 72 ft
60				
70				
80				Greenish-gray fine to coarse sand and shells from 72 to 110 ft
90				

LITHOLOGY SAMPLING RECORD

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Depth (feet)	Sampler Blows	Percent Recovery	Sample ID	Sample Description
100				
110				
	Pushed sampler	100	9	Green silty fine sand
120				
				Green silty fine sand from 110 to 164 ft
130				
140				
150				
160				
				Limestone from 164 to 165 ft
165				
				See logs for wells A2B1 and A2B3 for sampling above 40 ft

LITHOLOGY SAMPLING RECORD Page 1 of 1

Well ID:	A2C1	Date well drilled:	June 1, 1984
Client:	EPA	Borehole depth:	13.0 ft
Location:	Atlantic Beach, NC	Drilling method:	Auger
Project No.:	172	Sampling method:	Split spoon
Geologist:	T. Corwin	Driller:	A-C Borings, Inc.

Depth (feet)	Sampler Blows	Percent Recovery	Sample ID	Sample Description
0				Light brown fine sand to 2 ft, then gray fine sand to 5 ft
5	1/6/5	100	2	Tan to gray fine to medium sand

LITHOLOGY SAMPLING RECORD

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Well ID:	A2C3	Date well drilled:	May 24, 1984
Client:	EPA	Borehole depth:	31.5 ft
Location:	Atlantic Beach, NC	Drilling method:	Mud rotary
Project No.:	172	Sampling method:	Split spoon
Geologist:	T. Corwin	Driller:	A-C Borings, Inc.

Depth (feet)	Sampler Blows	Percent Recovery	Sample ID	Sample Description
10	2/1/1	40	3	Very loose gray fine sand
15	14/16/16	50	4	Dense gray fine sand
20	13/16/22	35	5	Dense gray fine sand with a trace of shells
				Clayey silt starts at 23 ft
25	1/4/12	100	6	Soft gray clayey silt from 25.0 to 25.7 ft, then firm gray silty fine sand from 25.7 to 26.5 ft
30	2/1/1	100	7	Loose gray silty fine sand from 30.0 to 31.2 ft, then soft gray clayey silt from 31.2 to 31.5 ft

LITHOLOGY SAMPLING RECORD Page 1 of 2

Well ID:	A2C4	Date well drilled:	June 6, 1984
Client:	EPA	Borehole depth:	75.0 ft
Location:	Atlantic Beach, NC	Drilling method:	Mud rotary
Project No.:	172	Sampling method:	Split spoon
Geologist:	T. Corwin	Driller:	A-C Borings, Inc.

Depth (feet)	Sampler Blows	Percent Recovery	Sample ID	Sample Description
30				Soft gray clayey silt and gray silty fine sand from 31.5 to 40 ft
35				
40	Pushed sampler	100	8	Soft gray clay
45				
50				Clayey silt and silty sand from 41.5 to 60 ft
55				

LITHOLOGY SAMPLING RECORD

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Depth (feet)	Sampler Blows	Percent Recovery	Sample ID	Sample Description
60				
65				Gray fine to medium sand and shells from 60 to 75 ft
70				
75				See logs for wells A2C1 and A2C3 for sampling from land surface to 30 ft

LITHOLOGY SAMPLING RECORDS
FOR
PINE KNOLL SHORES

LITHOLOGY SAMPLING RECORD

Well ID: P1A2	Date well drilled: June 4, 1984
Client: EPA	Borehole depth: 45.0 ft
Location: Pine Knoll Shores, NC	Drilling method: Mud rotary
Project No.: 172	Sampling method: Cuttings
Geologist: J. Fish	Driller: A-C Borings, Inc.

Depth (feet)	Sampler Blows	Percent Recovery	Sample ID	Sample Description
0	Sampled cuttings		1	Tan sand and crushed limestone (Fill material)
5	Sampled cuttings		2	Tan fine sand

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LITHOLOGY SAMPLING RECORD

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Well ID: P1A3	Date well drilled: June 4, 1984
Client: EPA	Borehole depth: 66.5 ft
Location: Pine Knoll Shores, NC	Drilling method: Mud rotary
Project No.: 172	Sampling method: Split spoon
Geologist: T. Corwin	Driller: A-C Borings, Inc.

Depth (feet)	Sampler Blows	Percent Recovery	Sample ID	Sample Description
10	6/8/8	35	3	Firm tan fine to medium sand Tan fine sand ends at 12.0 ft
15	21/41/ 50(4")	55	4	Very dense light gray fine to medium sand with shells
20	23/47/ 50(4")	75	5	Very dense light gray fine to medium sand with shells
25	27/50 (5")	75	6	Very dense light gray fine to medium sand with shells
30	18/29/34	60	7	Very dense light gray fine sand with some shells
35	12/16/19	60	8	Dense gray fine sand with a trace of shells

LITHOLOGY SAMPLING RECORD

Depth (feet)	Sampler Blows	Percent Recovery	Sample ID	Sample Description
40	11/24/ 50(5")	70	9	Very dense gray fine to medium sand
45	15/41/ 50(4")	65	10	Very dense gray fine sand
50	33/50 (4")	100	11	Very dense gray fine sand
55	33/50 (4")	80	12	Very dense gray fine sand
60	23/50 (6")	65	13	Very dense gray fine sand with a trace of shells
65	3/4/4	100	14	Gray clay with some fine sand
				See log for well P1A2 for sampling from land surface to 5 ft

LITHOLOGY SAMPLING RECORD

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Well ID:	P1B1	Date well drilled:	May 26, 1984
Client:	EPA	Borehole depth:	19.0 ft
Location:	Pine Knoll Shores, NC	Drilling method:	Auger
Project No.:	172	Sampling method:	Cuttings Examination
Geologist:	J. Fish	Driller:	A-C Borings, Inc.

Depth (feet)	Sampler Blows	Percent Recovery	Sample ID	Sample Description
0				
				Light brown fine sand from 0 to 2 ft
5				Tan fine sand with some shells from 2 to 16 ft
10				
15				
				Tan to gray fine to medium sand with some shells from 16 to 17 ft
19				Tan fine sand with some shells from 17 to 19 ft

LITHOLOGY SAMPLING RECORD

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Well ID:	P1C1	Date well drilled:	May 27, 1984
Client:	EPA	Borehole depth:	13.0 ft
Location:	Pine Knoll Shores, NC	Drilling method:	Auger
Project No.:	172	Sampling method:	Split spoon
Geologist:	J. Fish	Driller:	A-C Borings, Inc.

Depth (feet)	Sampler Blows	Percent Recovery	Sample ID	Sample Description
0	Pushed sampler	100	1	Tan to dark brown fine sand
5	2/4/6	100	2	Dark brown fine sand with lenses of organic silt
10	1/5/4	100	3	Gray to green fine sand with lenses of organic silt

LITHOLOGY SAMPLING RECORD

Well ID:	P1C3	Date well drilled:	May 22, 1984
Client:	EPA	Borehole depth:	66.5 ft
Location:	Pine Knoll Shores, NC	Drilling method:	Mud rotary
Project No.:	172	Sampling method:	Split spoon
Geologist:	T. Corwin	Driller:	A-C Borings, Inc.

Depth (feet)	Sampler Blows	Percent Recovery	Sample ID	Sample Description
11	1	100	3A	Tan fine sand and silt
15	12/21/24	60	4	Dense light gray fine sand
20	15/23/29	60	5	Dense gray fine to medium sand with some shells
25	12/18/26	100	6	Firm to dense gray fine to medium sand
30	8/12/18	70	7	Dense gray fine sand with a trace of silt
35	14/34/50	80	8	Very dense fine to medium sand with shells

LITHOLOGY SAMPLING RECORD

Depth (feet)	Sampler Blows	Percent Recovery	Sample ID	Sample Description
40	13/25/35	50	9	Very dense gray fine sand
45	19/44/ 50(5")	60	10	Very dense light gray fine sand with some shells
50	20/12/28	80	11	Dense gray medium sand with shells
55	10/19/40	80	12	Very dense gray medium sand with shells Clay starts at 58 ft
60	1/6/6	90	13	Soft gray interbedded clay, silt, and silty fine sand
65	Pushed sampler	65	14	No recovery. Trace amount of clay on spoon

LITHOLOGY SAMPLING RECORD

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Well ID:	P1C4	Date well drilled:	June 12, 1984
Client:	EPA	Borehole depth:	79.0 ft
Location:	Pine Knoll Shores, NC	Drilling method:	Mud rotary
Project No.:	172	Sampling method:	Cuttings Examination
Geologist:	T. Corwin, J. Fish	Driller:	A-C Borings, Inc.

Depth (feet)	Sampler Blows	Percent Recovery	Sample ID	Sample Description
70				Fine to medium sand from 69 to 73 ft
75				Green silt and fine sand from 73 to 79 ft
79				See logs for wells P1C1 and P1C3 for sampling from land surface to 65 ft

LITHOLOGY SAMPLING RECORD

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Well ID:	P1D1	Date well drilled:	May 26, 1984
Client:	EPA	Borehole depth:	15.0 ft
Location:	Pine Knoll Shores, NC	Drilling method:	Auger
Project No.:	172	Sampling method:	Cuttings Examination
Geologist:	J. Fish	Driller:	A-C Borings, Inc.

Depth (feet)	Sampler Blows	Percent Recovery	Sample ID	Sample Description
0				
				Dark brown fine sand from 0 to 6 ft
5				
				Dark brown organic silt from 6 to 6.5 ft
10				Light brown fine sand with shells from 6.5 to 15 ft
15				

LITHOLOGY SAMPLING RECORD

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Well ID:	P1E2	Date well drilled:	May 26, 1984
Client:	EPA	Borehole depth:	35.0 ft
Location:	Pine Knoll Shores, NC	Drilling method:	Mud rotary
Project No.:	172	Sampling method:	Split spoon
Geologist:	J. Fish	Driller:	A-C Borings, Inc.

Depth (feet)	Sampler Blows	Percent Recovery	Sample ID	Sample Description
0	Pushed sampler	60	1	Light brown fine sand from 0 to 0.6 ft, then gray fine sand from 0.6 to 1.5 ft
5	Pushed sampler	45	2	Brown fine sand

LITHOLOGY SAMPLING RECORD

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Well ID:	P1E3	Date well drilled:	May 25, 1984
Client:	EPA	Borehole depth:	61.5 ft
Location:	Pine Knoll Shores, NC	Drilling method:	Mud rotary
Project No.:	172	Sampling method:	Split spoon
Geologist:	T. Corwin	Driller:	A-C Borings, Inc.

Depth (feet)	Sampler Blows	Percent Recovery	Sample ID	Sample Description
10	3/6/7	45	3	Tan fine sand Gray fine sand probably starts at 12 ft
15	13/27/39	80	4	Dense gray fine sand
20	18/27/33	80	5	Dense gray fine sand with shells
25	10/21/25	80	6	Dense gray fine sand with shells
30	20/32/32	65	7	Dense gray medium sand with shells
35	-/24/ 50(5")	80	8	Medium sand and shells from 35.0 to 35.2 ft, then dense gray sand from 35.2 to 36.5 ft

LITHOLOGY SAMPLING RECORD

Depth (feet)	Sampler Blows	Percent Recovery	Sample ID	Sample Description
40	23/47/ 50(5")	70	9	Very dense gray fine to medium sand with shells
45	50(5")	85	10	Very dense gray medium sand with shells
50	20/24/ 50(5")	50	11	Very dense fine to medium gray sand with some shells
55	17/25/31	55	12	Dense gray medium sand with shells Silt at 57 ft
60	Pushed sampler	100	13	Soft interbedded gray clay, clayey silt and silty sand
				See log for well P1E2 for sampling from land surface to 5 ft

LITHOLOGY SAMPLING RECORD

Well ID: P2A1	Date well drilled: June 6, 1984
Client: EPA	Borehole depth: 20.0 ft
Location: Pine Knoll Shores, NC	Drilling method: Auger
Project No.: 172	Sampling method: Cuttings
Geologist: T. Corwin	Driller: A-C Borings, Inc.

Depth (feet)	Sampler Blows	Percent Recovery	Sample ID	Sample Description
0	Sampled cuttings		1	Tan fine to medium sand
5	Sampled cuttings		2	Light brown to tan fine to medium sand with some shells

LITHOLOGY SAMPLING RECORD

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Well ID:	P2A3	Date well drilled:	June 5, 1984
Client:	EPA	Borehole depth:	67.0 ft
Location:	Pine Knoll Shores, NC	Drilling method:	Mud rotary
Project No.:	172	Sampling method:	Split spoon
Geologist:	J. Fish, T. Corwin	Driller:	A-C Borings, Inc.

Depth (feet)	Sampler Blows	Percent Recovery	Sample ID	Sample Description
10	6/10/13	55	3	Tan to light brown fine to medium sand with some shells
15	4/8/16	65	4	Firm tan to light brown fine to medium sand with some shells
20	23/50	100	5	Very dense tan to light brown fine to medium sand with some shells
25	35/50 (5")	90	6	Very dense tan to light brown fine to medium sand with some shells
30	22/31/ 50(5")	70	7	Dense tan to gray medium sand with shells from 30 to 30.2 ft, then dense gray fine sand from 30.2 to 31.5 ft
35	19/15/28	65	8	Dense gray fine sand with shells

LITHOLOGY SAMPLING RECORD Page 2 of 2

Depth (feet)	Sampler Blows	Percent Recovery	Sample ID	Sample Description
40	11/17/23	80	9	Dense gray fine sand with a trace of shells
45	12/20/29	55	10	Dense gray fine sand with a trace of shells
50	12/23/35	50	11	Very dense fine sand with a trace of shells
55	22/35/ 50(4")	70	12	Very dense gray fine sand with a trace of shells
60	21/24/30	60	13	Dense gray fine sand with a trace of shells
65	Pushed sampler	100	14	Soft gray clayey and silty fine sand
				See log for well P2A1 for sampling from land surface to 5 ft

LITHOLOGY SAMPLING RECORD

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Well ID: P2B1	Date well drilled: May 27, 1984
Client: EPA	Borehole depth: 16.5 ft
Location: Pine Knoll Shores, NC	Drilling method: Auger
Project No.: 172	Sampling method: Cuttings Examination
Geologist: J. Fish	Driller: A-C Borings, Inc.

Depth (feet)	Sampler Blows	Percent Recovery	Sample ID	Sample Description
0				
5				Tan to light brown fine sand from 0 to 12 ft
10				
15				Gray fine to medium sand with a trace of shells from 12 to 16.5 ft
16.5				

LITHOLOGY SAMPLING RECORD

Well ID:	P2C3	Date well drilled:	May 23, 1984
Client:	EPA	Borehole depth:	51.5 ft
Location:	Pine Knoll Shores, NC	Drilling method:	Mud rotary
Project No.:	172	Sampling method:	Split spoon
Geologist:	J. Fish	Driller:	A-C Borings, Inc.

Depth (feet)	Sampler Blows	Percent Recovery	Sample ID	Sample Description
0	Pushed sampler	25	1	Light to dark brown fine sand with some organic silt
5				No sample
10	1/3/4	50	3	Dark brown fine sand and organic silt
15	17/20/23	40	4	Dense gray fine to medium sand
20	13/21/28	60	5	Dense gray fine sand
25	11/20/29	65	6	Dense gray fine sand

LITHOLOGY SAMPLING RECORD Page 2 of 2

Depth (feet)	Sampler Blows	Percent Recovery	Sample ID	Sample Description
30	17/23/41	65	7	Very dense gray fine sand with a trace of shells
35	6/7/12	100	8	Firm gray fine sand
40	5/6/4	80	9	Stiff gray fine sandy silt from 40 to 40.5 ft, then gray fine sand from 40.5 to 41.5 ft
45	1/1/1	40	10	Very soft gray clay
50	1/1/1	100	11	Very soft gray clay

LITHOLOGY SAMPLING RECORD Page 1 of 1

Well ID: P2C4	Date well drilled: June 11, 1984
Client: EPA	Borehole depth: 75.0 ft
Location: Pine Knoll Shores, NC	Drilling method: Mud rotary
Project No.: 172	Sampling method: Split spoon
Geologist: T. Corwin	Driller: A-C Borings, Inc.

Depth (feet)	Sampler Blows	Percent Recovery	Sample ID	Sample Description
50				Firm gray silty fine sand with shells from 51.5 to 65 ft
55				
60				
65	Pushed sampler	20	12	Firm gray silty fine sand with shells
70				Firm gray silty fine sand with shells from 66.5 to 75 ft
75				See log for well P2C3 for sampling from land surface to 55 ft

LITHOLOGY SAMPLING RECORD

Well ID:	P2D1	Date well drilled:	June 2, 1984
Client:	EPA	Borehole depth:	15.0 ft
Location:	Pine Knoll Shores, NC	Drilling method:	Auger
Project No.:	172	Sampling method:	Cuttings Examination
Geologist:	T. Corwin	Driller:	A-C Borings, Inc.

Depth (feet)	Sampler Blows	Percent Recovery	Sample ID	Sample Description
0				Light brown fine sand from 0 to 7.5 ft
5				
10				Light brown fine sand with a trace of silt from 7.5 to 15 ft
15				

LITHOLOGY SAMPLING RECORD

Well ID:	P2E1	Date well drilled:	June 2, 1984
Client:	EPA	Borehole depth:	15.0 ft
Location:	Pine Knoll Shores, NC	Drilling method:	Auger
Project No.:	172	Sampling method:	Cuttings and Split spoon
Geologist:	T. Corwin	Driller:	A-C Borings, Inc.

Depth (feet)	Sampler Blows	Percent Recovery	Sample ID	Sample Description
0	Sampled cuttings		1	Black loamy silt
5	Pushed sampler	100	2	Brown silty sand from 5 to 5.5 ft, then brown peat from 5.5 to 6.5 ft

LITHOLOGY SAMPLING RECORD Page 1 of 2

Well ID:	P2E3	Date well drilled:	June 2, 1984
Client:	EPA	Borehole depth:	51.5 ft
Location:	Pine Knoll Shores, NC	Drilling method:	Mud rotary
Project No.:	172	Sampling method:	Split spoon
Geologist:	T. Corwin	Driller:	A-C Borings, Inc.

Depth (feet)	Sampler Blows	Percent Recovery	Sample ID	Sample Description
10	9/12/8	40	3	Firm tan to light gray fine sand with a trace of silt
15	1/2/5	85	4	Loose tan to light gray fine sand with a trace of silt
20	13/24/25	70	5	Dense gray fine to medium sand with shells
25	19/34/39	85	6	Very dense gray fine to medium sand with shells
30	11/19/23	80	7	Dense gray fine to medium sand with shells
35	17/23/28	30	8	Dense gray fine to medium sand with shells

LITHOLOGY SAMPLING RECORD

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Depth (feet)	Sampler Blows	Percent Recovery	Sample ID	Sample Description
40	8/41/ 50(5")	85	9	Very dense gray fine sand
45	1/3/2	90	10	Loose gray silty fine sand
50	Pushed sampler	100	11	Soft gray clay
				See log for well P2E1 for sampling from land surface to 5 ft

LITHOLOGY SAMPLING RECORDS

FOR

SURF CITY

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LITHOLOGY SAMPLING RECORD

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Well ID:	S1A1	Date well drilled:	June 28, 1984
Client:	EPA	Borehole depth:	15.0 ft
Location:	Surf City, NC	Drilling method:	Auger
Project No.:	172	Sampling method:	Wash cuttings
Geologist:	T. Corwin	Driller:	A-C Borings, Inc.

Depth (feet)	Sampler Blows	Percent Recovery	Sample ID	Sample Description
0	Sampled cuttings		1	Tan fine sand

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LITHOLOGY SAMPLING RECORD

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Well ID: S1A2A (Abandoned)	Date well drilled: July 31, 1984
Client: EPA	Borehole depth: 11.5 ft
Location: Surf City, NC	Drilling method: Auger
Project No.: 172	Sampling method: Split spoon
Geologist: J. Fish	Driller: A-C Borings, Inc.

Depth (feet)	Sampler Blows	Percent Recovery	Sample ID	Sample Description
0				
5	6/7/7	100	2	Tan fine to medium sand with some shells
10	2/4/6	100	3	White fine to medium sand with some shells

LITHOLOGY SAMPLING RECORD

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Well ID:	S1A2	Date well drilled:	July 5, 1984
Client:	EPA	Borehole depth:	41 ft
Location:	Surf City, NC	Drilling method:	Mud rotary
Project No.:	172	Sampling method:	Split spoon
Geologist:	J. Fish	Driller:	A-C Borings, Inc.

Depth (feet)	Sampler Blows	Percent Recovery	Sample ID	Sample Description
15	4/8/11	50	4	Firm white and brown fine to coarse sand and shells
20	15/24/27	60	5	Very dense tan fine to coarse sand with some shells
25	19/33/38	70	6	Very dense tan fine to medium sand with some shells
30	15/18/18	100	7	Very dense tan fine to medium sand with a trace of shells
35	17/16/8	30	8	Firm gray fine sand with some shells
40	24/50 (6")	100	9	Very dense gray fine sand from 40.0 to 40.5 ft, then gray fossiliferous limestone

LITHOLOGY SAMPLING RECORD

Page 1 of 1

Well ID: S1A3	Date well drilled: July 24, 1984
Client: EPA	Borehole depth: 60.0 ft
Location: Surf City, NC	Drilling method: Mud rotary
Project No.: 172	Sampling method: Cuttings examination
Geologist: J. Fish	Driller: A-C Borings, Inc.

Depth (feet)	Sampler Blows	Percent Recovery	Sample ID	Sample Description
45				Gray limestone from 41.5 to 50 ft
50				
55				Tan sandstone from 50 to 60 ft
60				See logs for wells S1A1, S1A2A and S1A2 for sampling from land surface to 40 ft

LITHOLOGY SAMPLING RECORD Page 1 of 1

Well ID:	S1B1	Date well drilled:	June 28, 1984
Client:	EPA	Borehole depth:	16.0 ft
Location:	Surf City, NC	Drilling method:	Auger
Project No.:	172	Sampling method:	Wash cuttings
Geologist:	T. Corwin	Driller:	A-C Borings, Inc.

Depth (feet)	Sampler Blows	Percent Recovery	Sample ID	Sample Description
0	Sampled cuttings		1	Brown fine to medium sand and shells
5	Sampled cuttings		2	Brown fine to medium sand and shells

LITHOLOGY SAMPLING RECORD

Page 1 of 1

Well ID:	S1B2	Date well drilled:	June 29, 1984
Client:	EPA	Borehole depth:	33.0 ft
Location:	Surf City, NC	Drilling method:	Mud rotary
Project No.:	172	Sampling method:	Split spoon
Geologist:	J. Fish	Driller:	A-C Borings, Inc.

Depth (feet)	Sampler Blows	Percent Recovery	Sample ID	Sample Description
10	8/9/9	50	3	Firm brown medium sand and shells
15	6/10/16	45	4	Firm gray and brown coarse sand and shells
20	4/6/8	40	5	Firm gray coarse sand and shells
25	12/14/17	50	6	Dense gray medium sand
30	14/24/25	40	7	Dense light gray fine sand

LITHOLOGY SAMPLING RECORD Page 1 of 1

Well ID:	S1B3	Date well drilled:	July 24, 1984
Client:	EPA	Borehole depth:	70.0 ft
Location:	Surf City, NC	Drilling method:	Mud rotary
Project No.:	172	Sampling method:	Cuttings examination
Geologist:	T. Corwin	Driller:	A-C Borings, Inc.

Depth (feet)	Sampler Blows	Percent Recovery	Sample ID	Sample Description
30				Dark gray fine sandy silt from 33 to 36 ft
40				Light gray limestone from 36 to 53 ft
50				
60				Tan sandstone from 53 to 70 ft
70				See logs for wells S1B1 and S1B2 and for sampling from land surface to 30 ft

LITHOLOGY SAMPLING RECORD

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Well ID:	S3A1	Date well drilled:	June 28, 1984
Client:	EPA	Borehole depth:	20.0 ft
Location:	Surf City, NC	Drilling method:	Auger
Project No.:	172	Sampling method:	Wash cuttings
Geologist:	T. Corwin	Driller:	A-C Borings, Inc.

Depth (feet)	Sampler Blows	Percent Recovery	Sample ID	Sample Description
0	Sampled cuttings		1	Tan fine to medium sand with some shells
5	Sampled cuttings		2	Tan to brown fine to medium sand with some shells

LITHOLOGY SAMPLING RECORD

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Well ID: S3A2	Date well drilled: July 9, 1984
Client: EPA	Borehole depth: 34.0 ft
Location: Surf City, NC	Drilling method: Mud rotary
Project No.: 172	Sampling method: Split spoon
Geologist: J. Fish, T. Corwin	Driller: A-C Borings, Inc.

Depth (feet)	Sampler Blows	Percent Recovery	Sample ID	Sample Description
10	7/5/6	20	3	Firm gray and brown fine to medium sand with a trace of shells
15	7/11/13	35	4	Firm gray fine to coarse sand with some shells
20	7/8/11	30	5	Firm gray fine to coarse sand with some shells
25	14/17/24	55	6	Dense tan medium to coarse sand and shells
30	7/8/8	50	7	Firm tan medium to coarse sand and shells

LITHOLOGY SAMPLING RECORD

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Well ID:	S3A3	Date well drilled:	July 18, 1984
Client:	EPA	Borehole depth:	70.0 ft
Location:	Surf City, NC	Drilling method:	Mud rotary
Project No.:	172	Sampling method:	Cuttings examination
Geologist:	T. Corwin	Driller:	A-C Borings, Inc.

Depth (feet)	Sampler Blows	Percent Recovery	Sample ID	Sample Description
30				
				Dark gray fine sandy silt from 33 to 38 ft
40				
				Light gray limestone from 38 to 56 ft
50				
				Interbedded limestone and very fine sand from 56 to 65 ft
60				
				Interbedded limestone and very fine sand from 65 to 70 ft
70				
				See logs for wells S3A1 and S3A2 for sampling from land surface to 30 ft

LITHOLOGY SAMPLING RECORD

Page 1 of 1

Well ID: S3B1	Date well drilled: July 16, 1984
Client: EPA	Borehole depth: 18.0 ft
Location: Surf City, NC	Drilling method: Mud rotary
Project No.: 172	Sampling method: Cuttings examination
Geologist: T. Corwin	Driller: A-C Borings, Inc.

Depth (feet)	Sampler Blows	Percent Recovery	Sample ID	Sample Description
0				
				Tan fine to medium sand with some shells from 0 to 6 ft
5				
				Gray fine to medium sand with some shells from 6 to 10 ft
10				

LITHOLOGY SAMPLING RECORD

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Well ID:	S3B3	Date well drilled:	June 26, 1984
Client:	EPA	Borehole depth:	52.0 ft
Location:	Surf City, NC	Drilling method:	Mud rotary
Project No.:	172	Sampling method:	Split spoon
Geologist:	J. Fish, T. Corwin	Driller:	A-C Borings, Inc.

Depth (feet)	Sampler (Blows)	Percent Recovery	Sample ID	Sample Description
10	15/21/25	50	3	Dense gray fine to medium sand with some shells
15	10/15/19	50	4	Dense gray fine to medium sand with some shells
20	17/30/32	55	5	Shells from 20.0 to 20.4 ft, then very dense gray fine to medium sand from 20.4 to 21.5 ft
25	14/19/28	60	6	Shells from 25.0 to 25.6 ft, then light gray fine to medium sand from 25.6 to 26.5 ft
30	16/16/14	20	7	Dense light gray fine to medium sand
				Silty clay encountered from 31 to 34 ft, then limestone
35	50(5.5")	90	8	Light gray limestone

LITHOLOGY SAMPLING RECORD

Page 1 of 2

Well ID:	S3B4	Date well drilled:	July 4, 1984
Client:	EPA	Borehole depth:	135.0 ft
Location:	Surf City, NC	Drilling method:	Mud rotary
Project No.:	172	Sampling method:	Cuttings examination
Geologist:	T. Corwin	Driller:	A-C Borings, Inc.

Depth (feet)	Sampler Blows	Percent Recovery	Sample ID	Sample Description
40				Light gray limestone from 34 to 60 ft
50				
60				
70				Interbedded gray limestone and green sandstone from 60 to 75 ft
80				
90				Green sandstone from 75 to 113 ft

LITHOLOGY SAMPLING RECORD

Depth (feet)	Sampler Blows	Percent Recovery	Sample ID	Sample Description
100				
110				
120				Gray limestone from 113 to 135 ft
130				
135				
				See logs for wells S3B1 and S3B3 for sampling from land surface to 40 ft

LITHOLOGY SAMPLING RECORD

Page 1 of 1

Well ID: S3C1	Date well drilled: June 28, 1984
Client: EPA	Borehole depth: 16.0 ft
Location: Surf City, NC	Drilling method: Auger
Project No.: 172	Sampling method: Wash cuttings
Geologist: T. Corwin	Driller: A-C Borings, Inc.

Depth (feet)	Sampler Blows	Percent Recovery	Sample ID	Sample Description
0	Sampled cuttings		1	Black organic silt
5	Sampled cuttings		2	Gray silty fine to medium sand

LITHOLOGY SAMPLING RECORD

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Well ID:	S3C2	Date well drilled:	July 6, 1984
Client:	EPA	Borehole depth:	30.0 ft
Location:	Surf City, NC	Drilling method:	Mud rotary
Project No.:	172	Sampling method:	Split spoon
Geologist:	T. Corwin, J. Fish	Driller:	A-C Borings, Inc.

Depth (feet)	Sampler Blows	Percent Recovery	Sample ID	Sample Description
10	13/12/10	90	3	Firm gray fine to medium sand with some shells
15	5/7/11	55	4	Firm gray fine to medium sand with some shells
20	20/22/26	50	5	Dense gray fine to medium sand with some shells
25	3/8/10	65	6	Firm gray fine sand
				Gray silty clay from 27 to 30 ft
30				

LITHOLOGY SAMPLING RECORD Page 1 of 1

Well ID:	S3C3	Date well drilled:	July 17, 1984
Client:	EPA	Borehole depth:	80.0 ft
Location:	Surf City, NC	Drilling method:	Mud rotary
Project No.:	172	Sampling method:	Cuttings examination
Geologist:	T. Corwin	Driller:	A-C Borings, Inc.

Depth (feet)	Sampler Blows	Percent Recovery	Sample ID	Sample Description
30				Light gray limestone from 30 to 43 ft
40				Tan sandstone from 43 to 48 ft
50				
60				Interbedded sandstone and limestone from 48 to 70 ft
70				Green partially consolidated sand and sandstone from 70 to 80 ft
80				See logs for wells S3C1 and S3C2 for sampling from land surface to 30 ft

APPENDIX C

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SECTION 1

AQUIFER PUMPING TEST

AT

KILL DEVIL HILLS

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AQUIFER PUMPING TESTS

One aquifer pumping test was conducted in each of the three study areas. Eight-hour tests were conducted in Kill Devil Hills and Pine Knoll Shores. A four-hour test was conducted in Surf City. These tests are described in the sections that follow.

The pumping rate to be used for each of the tests was determined prior to testing. The pumping capacity of each test well was determined by pumping the well at various rates while observing drawdowns in the well. This information was used to determine a pumping rate for testing that would assure that the well would produce the maximum amount of water possible without creating excessive drawdowns in the well. This preliminary testing was done the day before conducting the aquifer pumping test.

AQUIFER PUMPING TEST AT KILL DEVIL HILLS, NC

An 8-hour aquifer pumping test was performed on 16 May 1984 in Kill Devil Hills, NC. Pumping began at 0700 Eastern Daylight Time (EDT) and lasted until 1510 EDT. Well K3D2 was the pumped well. The average pumping rate from the well was 28.5 gallons per minute (gpm). The pumped water was discharged to the ground surface approximately 260 feet south of the well. Wells K3D1 and K3D3 were used as observation wells.

Well construction details for the pumped well and the observation wells varied between wells. Well K3D1 is completed in unconsolidated sand deposits near the water table surface. There is a one to two foot thick layer of peat material that starts about four feet below the base of this well. Well K3D3 is completed in unconsolidated sand deposits near the top of a clayey sand that is approximately 77 feet below the water table. Well K3D2 is completed in unconsolidated sand deposits between the clayey sand and the peat material. Construction details for the wells are summarized in Table 1. A cross section showing the lithology at the site and the spacial relationship between wells is given in Figure 1.

Water levels were measured in the pumped well and each of the observation wells. Water level declines were observed in the pumped well and in observation well K3D3. The water level in observation well K3D1 remained approximately constant during the pumping period. The observed water levels and computed water level changes during pumping are presented at the end of this section.

The computed transmissivity and hydraulic conductivity for the unconsolidated deposits are 10,900 gallons per day per foot (gpd/ft) and 545 gallons per day per foot squared (gpd/ft2). The effective aquifer thickness used for the hydraulic conductivity computation was 20 feet, which is the length of the screened interval in the pumped well. The behavior of water levels in observation wells K3D1 and K3D3 during testing indicated that most of the water being extracted from these deposits in the pumping well vicinity was probably the result of horizontal flow to the well within the area of the screened interval. Layering of the sands and shells in the aquifer promotes the horizontal flow of water while minimizing the vertical flow.

The modified Theis nonequilibrium analysis (Ferris et. al., 1962) and the Theis recovery analysis (Ferris et al., 1962), together with water level data for the pumped well, were used to compute the transmissivity of the unconsolidated deposits. Hydraulic conductivity for these deposits was estimated based on the computed transmissivity and estimated effective saturated thickness in the vicinity of the well.

The aquifer pumping test analysis is presented at the end of this section.

The data collected at observation well K3D3 were not used for determining the hydraulic properties of the unconsolidated deposits. A preliminary analysis using the water level data from this well indicated that the drawdowns in this well were strongly influenced by the partial penetration of the pumping well.

TABLE 1

WELL CONSTRUCTION SUMMARY

Well number	Well depth (feet)	Well diameter (inches)	Top of open interval below land surface (feet)	Screen length (feet)
K3D1	13.0	6	8.0	5.0
K3D2	46.5	4	26.5	20.0
K3D3	79.0	2	74.0	5.0

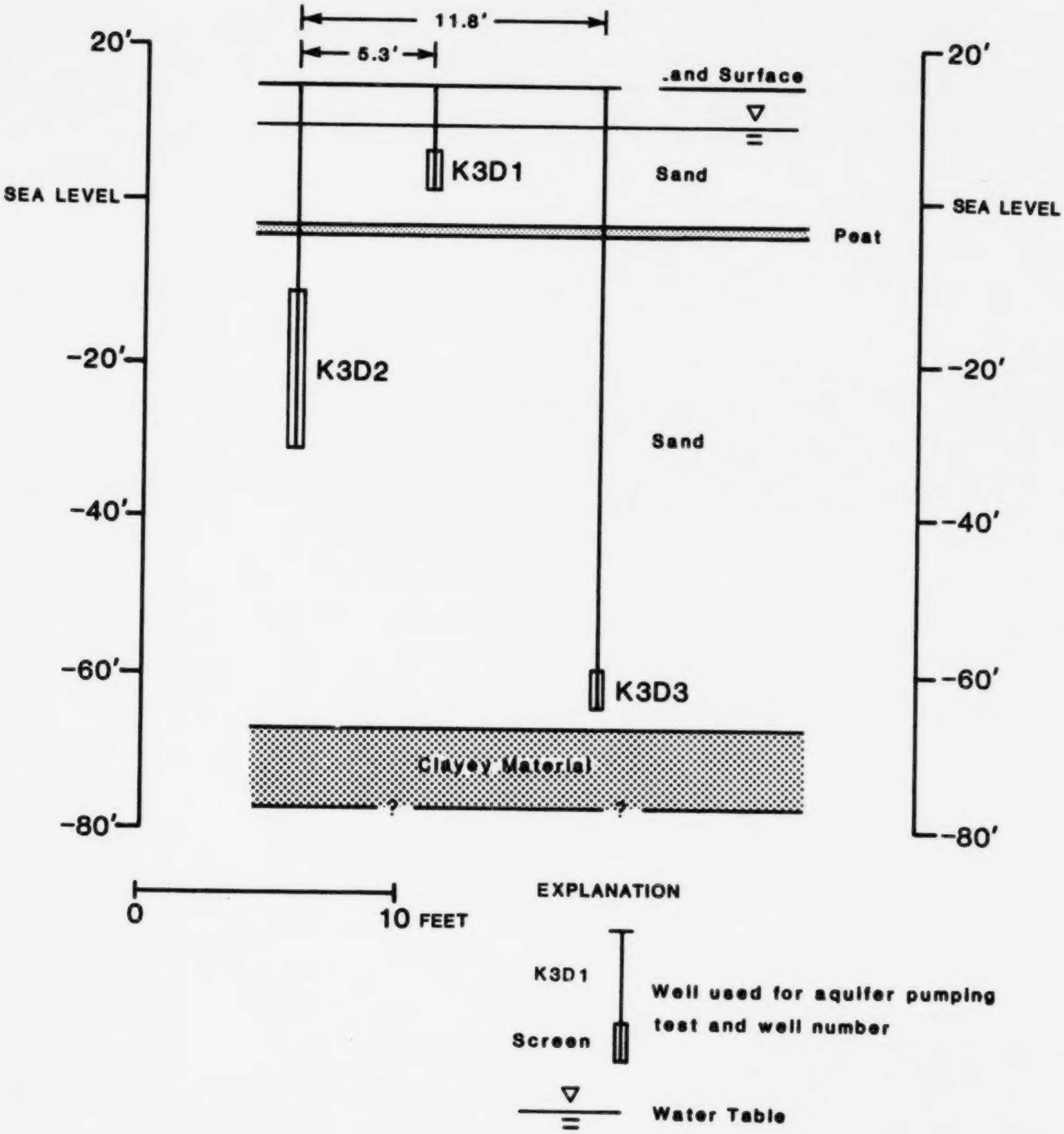
11.8'
5.3'
20'
.and Surface
SEA LEVEL
K3D1
Sand
Peat
K3D2
-20'
Sand
-40'
-60'
K3D3
Clayey Material
?
-80'
0
10 FEET
EXPLANATION
K3D1
Well used for aquifer pumping test and well number
Screen
Water Table

Figure 1. Geologic cross-section in vicinity of aquifer pump test site at Kill Devil Hills, N.C.

The data collected at observation well K3D1 indicates that the unconsolidated deposits that lie below the peat layer are hydraulically separated from those that lie above this layer. The water level in this observation well did not change significantly during the pumping period. This well is completed in the unconsolidated deposits above the peat layer. The water level data collected at this well, although qualitatively informative, could not be used for any type of quantitative analyses.

REFERENCES

Ferris, J.B. et al. 1962. Theory of aquifer tests: United States Geological Survey Water Supply Paper 1536-E.

WATER LEVELS FOR AQUIFER PUMPING TEST

Water levels were recorded for the pumped well (Well K3D2) and for wells K3D1 and K3D3. These data are tabulated for each well in the tables which follow. In these tables, the column headings have the following meaning:

Date:	Date of reading.
Time:	Time of reading, Eastern Daylight Time (EDT).
Depth to water:	The depth to water below the measuring point, in feet.
Flow meter reading: (pumped well only)	The total gallons of water recorded by the flow meter. The meter reading was 339752.5 gallons prior to beginning the test.
Remarks:	Any pertinent remarks.

TABLE A1
WATER LEVEL AND PUMPING DATA FOR WELL K302

Date (1984)	Time (EDT)	Depth to water (feet)	Flow meter reading (gallons)	Remarks
May 16	0625	5.85		
	0658	5.85		
	0700	-	339752.5	Pump on
	0700:10	12.00		
	0700:30	14.10		
	0701	14.59		
	0702	15.00		Measure 28.7 gpm using flow meter
	0703	15.53		
	0704:15	15.65		
	0705	15.79		
	0706	15.79		
	0707	15.97		
	0708	15.91		Measure 29.0 gpm using flow meter Adjust pump
	0709	15.96		
	0710:05	16.02		
	0711:15	15.94		
	0712	15.89		Measure 28.3 gpm using flow meter Adjust pump
	0713	15.91		Measure 27.9 gpm using flow meter Adjust pump
	0714	16.18		Measure 28.7 gpm using flow meter Adjust pump
	0715	16.10		
	0716:38	16.06		
	0718	-		Measure 27.9 gpm using flow meter Adjust pump
	0718:15	15.93		
	0719:38	16.04		
	0720	-		Measure 28.0 gpm using flow meter Adjust pump
	0721	16.30		Measure 28.8 gpm using flow meter
	0723	16.29		
	0728	16.31		
	0730	16.35		
	0734	16.38		
	0736	16.39		
	0738	16.40		
	0740	16.43		
	0743	16.43		
	0747	16.37		Measure 28.4 gpm using flow meter
	0750	16.34		
	0751	-		Measure 28.4 gpm using flow meter
	0755	16.39		
	0756	-		Measure 28.3 gpm using flow meter
	0800	16.39	3399236.5	
	0803	-		Measure 28.6 gpm using flow meter
	0811	16.38		Measure 28.2 gpm using flow meter
	0820	16.47		
	0826	-		Measure 28.0 gpm using flow meter
	0830	16.45		
	0831	-		Measure 28.3 gpm using flow meter
	0840	16.52		
	0850	16.58		
	0855	-		Measure 28.2 gpm using flow meter
	0900	16.60	3400914.2	
	0913	-		Measure 28.6 gpm using flow meter
	0915	16.83		
	0927	-		Measure 28.4 gpm using flow meter
	0930	16.79		
	0945	16.88		
	0946	-		Measure 28.8 gpm using flow meter
	1000	16.87	3402631.0	
	1016	17.14		
	1020	17.17		
	1021	-		Measure 29.3 gpm using flow meter

TABLE A1
(continued)
WATER LEVEL AND PUMPING DATA FOR WELL K3D2

Date (1984)	Time (EDT)	Depth to water (feet)	Flow meter reading (gallons)	Remarks
May 16 (continued)	1030	17.10		Measure 29.3 gpm using flow meter
	1045	17.23		Measure 29.3 gpm using flow meter
	1052	17.17		
	1100	16.93	3404375.0	Measure 28.6 gpm using flow meter
	1110	-	3404659.0	
	1115	16.87		
	1130	17.11		Measure 29.0 gpm using flow meter
	1146	17.01		
	1149	-		Measure 28.6 gpm using flow meter
	1200	17.01	3406090.0	
	1215	17.00		
	1230	17.03		Measure 28.4 gpm using flow meter
	1245	17.04		
	1251	-		Measure 28.4 gpm using flow meter
	1300	17.01	3407801.0	
	1315	17.04		Measure 28.4 gpm using flow meter
	1330	17.02		
	1344	-		Measure 28.4 gpm using flow meter
	1345	17.02		
	1400	17.02	3409505.0	
	1404	-		Measure 28.4 gpm using flow meter
	1415	17.05		
	1430	17.08		
	1445	-		Measure 28.4 gpm using flow meter
	1500	17.00	3411209.0	
	1510	-	3411492.4	Pump off
	1510:06	13.00		
	1510:38	8.00		
	1511	7.68		
	1512:30	7.31		
	1513:40	7.18		
	1514	7.13		
	1515	7.07		
	1516	7.02		
	1517	6.95		
	1518	6.91		
	1519	6.87		
	1520	6.83		
	1522	6.79		
	1524	6.73		
	1527	6.69		
	1530	6.63		
	1534	6.57		
	1537	6.55		
	1540	6.51		
	1545	6.47		
	1552	6.42		
	1556	6.40		
	1600	6.36		
	1610	6.32		
	1626	6.25		
	1703	6.15		
	1730	6.12		

Total gallons pumped is 13,963.9 gallons
Average pumping rate is 28.5 gpm

TABLE A2

WATER LEVEL DATA FOR OBSERVATION WELL K3D1

Date (1984)	Time (EDT)	Depth to water (feet)	Remarks
May 16	0627	4.17	
	0656	4.16	
	0700	-	Pump on
	0709:45	4.16	
	0717:30	4.16	
	0723:48	4.16	
	0739	4.16	
	0749	4.16	
	0752	4.17	
	0802	4.16	
	0813	4.17	
	0836	4.16	
	0852	4.17	
	0901	4.17	
	0920	4.17	
	0935	4.18	
	0946	4.18	
	1001	4.18	
	1017	4.18	
	1031	4.17	
	1046	4.17	
	1101	4.17	
	1132	4.18	
	1201	4.18	
	1232	4.17	
	1301	4.18	
	1332	4.20	
	1400	4.18	
	1432	4.18	
	1501	4.18	
	1510	-	Pump off
	1514:34	4.18	
	1519:30	4.18	
	1528	4.18	
	1537	4.18	
	1547	4.18	
	1602	4.18	
	1611	4.18	
	1627	4.18	
	1704	4.18	
	1732	4.18	

TABLE A3

WATER LEVEL DATA FOR OBSERVATION WELL K3D3

Date (1984)	Time (EDT)	Depth to water (feet)	Remarks
May 16	0629	6.07	
	0657	6.07	
	0700	-	Pump on
	0703:45	6.03	
	0710:45	6.04	
	0715:50	6.04	
	0725:40	6.07	
	0732	6.07	
	0741	6.08	
	0748	6.09	
	0753	6.09	
	0804	6.11	
	0812	6.11	
	0821	6.13	
	0835	6.14	
	0851	6.15	
	0902	6.15	
	0918	6.18	
	0932	6.20	
	0947	6.20	
	1001	6.22	
	1017	6.23	
	1032	6.22	
	1046	6.25	
	1102	6.25	
	1116	6.27	
	1131	6.25	
	1148	6.27	
	1201	6.29	
	1216	6.28	
	1234	6.29	
	1247	6.30	
	1302	6.30	
	1317	6.31	
	1333	6.32	
	1347	6.31	
	1401	6.32	
	1417	6.32	
	1433	6.32	
	1502	6.34	
	1510	-	Pump off
	1511:44	6.37	
	1513:10	6.36	
	1515:23	6.37	
	1518:36	6.36	
	1521	6.34	
	1525	6.35	
	1532	6.34	
	1535	6.33	
	1546	6.31	
	1601	6.30	
	1611	6.30	
	1627	6.28	
	1704	6.24	
	1733	6.23	

DRAWDOWN COMPUTATIONS FOR AQUIFER PUMPING TEST

Drawdowns in the pumped well and the observation wells during the aquifer pumping test were computed based on the water level observations. The drawdown computations for each well are tabulated in the tables which follow. In these tables, the column headings have the following meaning:

Date:	Date of reading.
Time:	Time of reading, Eastern Daylight Time (EDT).
Δt:	Time from start of pumping, in minutes.
$\Delta t'$:	Time since pumping stopped, in minutes.
Depth to water:	Depth to water below the measuring point, in feet.
s:	Drawdown in water level, in feet. Drawdown is computed by subtracting the depth to water measured prior to starting the test from the depth to water. This drawdown is termed residual drawdown whenever $\Delta t'$ is greater than zero.
Remarks:	Any pertinent remarks.

TABLE B1

DRAWDOWN COMPUTATIONS FOR WELL K3D2

Date (1984)	Time (EDT)	Δt (min)	Δt' (min)	$\frac{\Delta t}{\Delta t'}$	Depth to water (feet)	s (feet)	Remarks
May 16	0625				5.85	0.00	Assume static water level
	0658				5.85	0.00	
	0700	0.0			-	-	Pump on
	0700:10	0.17			12.00	6.15	
	0700:30	0.50			14.10	8.25	
	0701	1.0			14.59	8.74	
	0702	2.0			15.00	9.15	
	0703	3.0			15.53	9.68	
	0704:15	4.25			15.65	9.80	
	0705	5.0			15.79	9.94	
	0706	6.0			15.79	9.94	
	0707	7.0			15.97	10.12	
	0708	8.0			15.91	10.06	
	0709	9.0			15.96	10.11	
	0710:05	10.08			16.02	10.17	
	0711:15	11.25			15.94	10.09	
	0712	12.0			15.89	10.04	
	0713	13.0			15.91	10.06	
	0714	14.0			16.18	10.33	
	0715	15.0			16.10	10.25	
	0716:38	16.6			16.06	10.21	
	0718:15	18.25			15.93	10.08	
	0719:38	19.6			16.04	10.19	
	0721	21.0			16.30	10.45	
	0723	23.0			16.29	10.44	
	0728	28.0			16.31	10.46	
	0730	30.0			16.35	10.50	
	0734	34.0			16.38	10.53	
	0736	36.0			16.39	10.54	
	0738	38.0			16.40	10.55	
	0740	40.0			16.43	10.58	
	0743	43.0			16.43	10.58	
	0747	47.0			16.37	10.52	
	0750	50.0			16.34	10.49	
	0755	55.0			16.39	10.54	
	0800	60.0			16.39	10.54	
	0811	71.0			16.38	10.53	
	0820	80.0			16.47	10.62	
	0830	90.0			16.45	10.60	
	0840	100			16.52	10.67	
	0850	110			16.58	10.73	
	0900	120			16.60	10.75	
	0915	135			16.83	10.98	
	0930	150			16.79	10.94	
	0945	165			16.88	11.03	
	1000	180			16.87	11.02	
	1016	196			17.14	11.29	
	1020	200			17.17	11.32	
	1030	210			17.10	11.25	
	1045	225			17.23	11.38	
	1052	232			17.17	11.32	
	1100	240			16.93	11.08	
	1115	255			16.87	11.02	
	1130	270			17.11	11.26	
	1146	286			17.01	11.16	
	1200	300			17.01	11.16	
	1215	315			17.00	11.15	
	1230	330			17.03	11.18	
	1245	345			17.04	11.19	
	1300	360			17.01	11.16	
	1315	375			17.04	11.19	

TABLE B1
(continued)
DRAWDOWN COMPUTATIONS FOR WELL K3D2

Date (1984)	Time (EDT)	Δt (min)	$\Delta t'$ (min)	$\frac{\Delta t}{\Delta t'}$	Depth to water (feet)	s (feet)	Remarks
May 16	1330	390			17.02	11.17	
(continued)	1345	405			17.02	11.17	
	1400	420			17.02	11.17	
	1415	435			17.05	11.20	
	1430	450			17.08	11.23	
	1500	480			17.00	11.15	
	1510	490					Pump off
	1510:06	490.1	0.1	4901	13.00	7.15	
	1510:38	490.6	0.6	818	8.00	2.15	
	1511	491	1.0	491	7.68	1.83	
	1512:30	492.5	2.5	197	7.31	1.46	
	1513:40	493.7	3.7	133	7.18	1.33	
	1514	494	4.0	123.5	7.13	1.28	
	1515	495	5.0	99.0	7.07	1.22	
	1516	496	6.0	82.7	7.02	1.17	
	1517	497	7.0	71.0	6.95	1.10	
	1518	498	8.0	62.2	6.91	1.06	
	1519	499	9.0	55.4	6.87	1.02	
	1520	500	10	50.0	6.83	0.98	
	1522	502	12	41.8	6.79	0.94	
	1524	504	14	36.0	6.73	0.88	
	1527	507	17	29.8	6.69	0.84	
	1530	510	20	25.5	6.63	0.78	
	1534	514	24	21.4	6.57	0.72	
	1537	517	27	19.1	6.55	0.70	
	1540	520	30	17.3	6.51	0.66	
	1545	525	35	15.0	6.47	0.62	
	1552	532	42	12.7	6.42	0.57	
	1556	536	46	11.7	6.40	0.55	
	1600	540	50	10.8	6.36	0.51	
	1610	550	60	9.2	6.32	0.47	
	1626	566	76	7.4	6.25	0.40	
	1703	603	113	5.3	6.15	0.30	
	1730	630	140	4.5	6.12	0.27	

TABLE B2

DRAWDOWN COMPUTATIONS FOR WELL K3D1

Date (1984)	Time (EDT)	Δt (min)	Depth to water (feet)	s (feet)	Remarks
May 16	0627		4.17		
	0656		4.16	0	Assume static water level
	0700	0.0			Pump on
	0709:45	9.75	4.16	0	
	0717:30	17.5	4.16	0	
	0723:48	23.8	4.16	0	
	0739	39.0	4.16	0	
	0749	49.0	4.16	0	
	0752	52.0	4.17	0.01	
	0802	62.0	4.16	0	
	0813	73.0	4.17	0.01	
	0836	96.0	4.16	0	
	0852	112	4.17	0.01	
	0901	122	4.17	0.01	
	0920	140	4.17	0.01	
	0935	155	4.18	0.02	
	0946	166	4.18	0.02	
	1001	181	4.18	0.02	
	1017	197	4.18	0.02	
	1031	211	4.17	0.01	
	1046	226	4.17	0.01	
	1101	241	4.17	0.01	
	1132	272	4.18	0.02	
	1201	301	4.18	0.02	
	1232	332	4.17	0.01	
	1301	361	4.18	0.02	
	1332	392	4.20	0.04	
	1400	420	4.18	0.02	
	1432	452	4.18	0.02	
	1501	481	4.18	0.02	
	1510	490	-	-	Pump off

TABLE B3

DRAWDOWN COMPUTATIONS FOR WELL K3D3

Date (1984)	Time (EDT)	Δt (min)	Depth to water (feet)	s (feet)	Remarks
May 16	0629		6.07		
	0657		6.07	0	Assume static water level
	0700	0			Pump on
	0703:45	3.75	6.03	-0.04	
	0710:45	10.75	6.04	-0.03	
	0715:50	15.83	6.04	-0.03	
	0725:40	25.67	6.07	0	
	0732	32.0	6.07	0	
	0741	41.0	6.08	0.01	
	0748	48.0	6.09	0.02	
	0753	53.0	6.09	0.02	
	0804	64.0	6.11	0.04	
	0812	72.0	6.11	0.04	
	0821	81.0	6.13	0.06	
	0835	95.0	6.14	0.07	
	0851	111	6.15	0.08	
	0902	122	6.15	0.08	
	0918	138	6.18	0.11	
	0932	152	6.20	0.13	
	0947	167	6.20	0.13	
	1001	181	6.22	0.15	
	1017	197	6.23	0.16	
	1032	212	6.22	0.15	
	1046	226	6.25	0.18	
	1102	242	6.25	0.18	
	1116	256	6.27	0.20	
	1131	271	6.25	0.18	
	1148	288	6.27	0.20	
	1201	301	6.29	0.22	
	1216	316	6.28	0.21	
	1234	334	6.29	0.22	
	1247	347	6.30	0.23	
	1302	362	6.30	0.23	
	1317	377	6.31	0.24	
	1333	393	6.32	0.25	
	1347	407	6.31	0.24	
	1401	421	6.32	0.25	
	1417	437	6.32	0.25	
	1433	453	6.32	0.25	
	1502	482	6.34	0.27	
	1510				Pump off

AQUIFER PUMPING TEST ANALYSIS

Water level data for the pumped well were used with the modified Theis nonequilibrium analysis to compute the transmissivity for the unconsolidated deposits. The form of the modified Theis nonequilibrium analysis formula used for the computations is:

$$T = \frac{264Q}{\Delta s}$$

The variables in the above equation have the following meaning:

T = transmissivity, in gallons per day per foot;

Q = average pumping rate, in gallons per minute; and

Δs = change in drawdown over one log-cycle for a semi-log plot of time and drawdown.

The Theis recovery analysis, together with water level recovery data for the pumped well, were also used to compute transmissivity. The form of the Theis recovery analysis formula used for the computations is the same as the modified Theis nonequilibrium analysis formula. However, for the Theis recovery analysis:

Δs = change in residual drawdown over one log-cycle for a semi-log plot of $\Delta t/\Delta t'$ and residual drawdown. Time since pumping began is defined as Δt and time since pumping stopped is defined as $\Delta t'$.

The data plots and data analyses are presented in Figures C1 and C2.

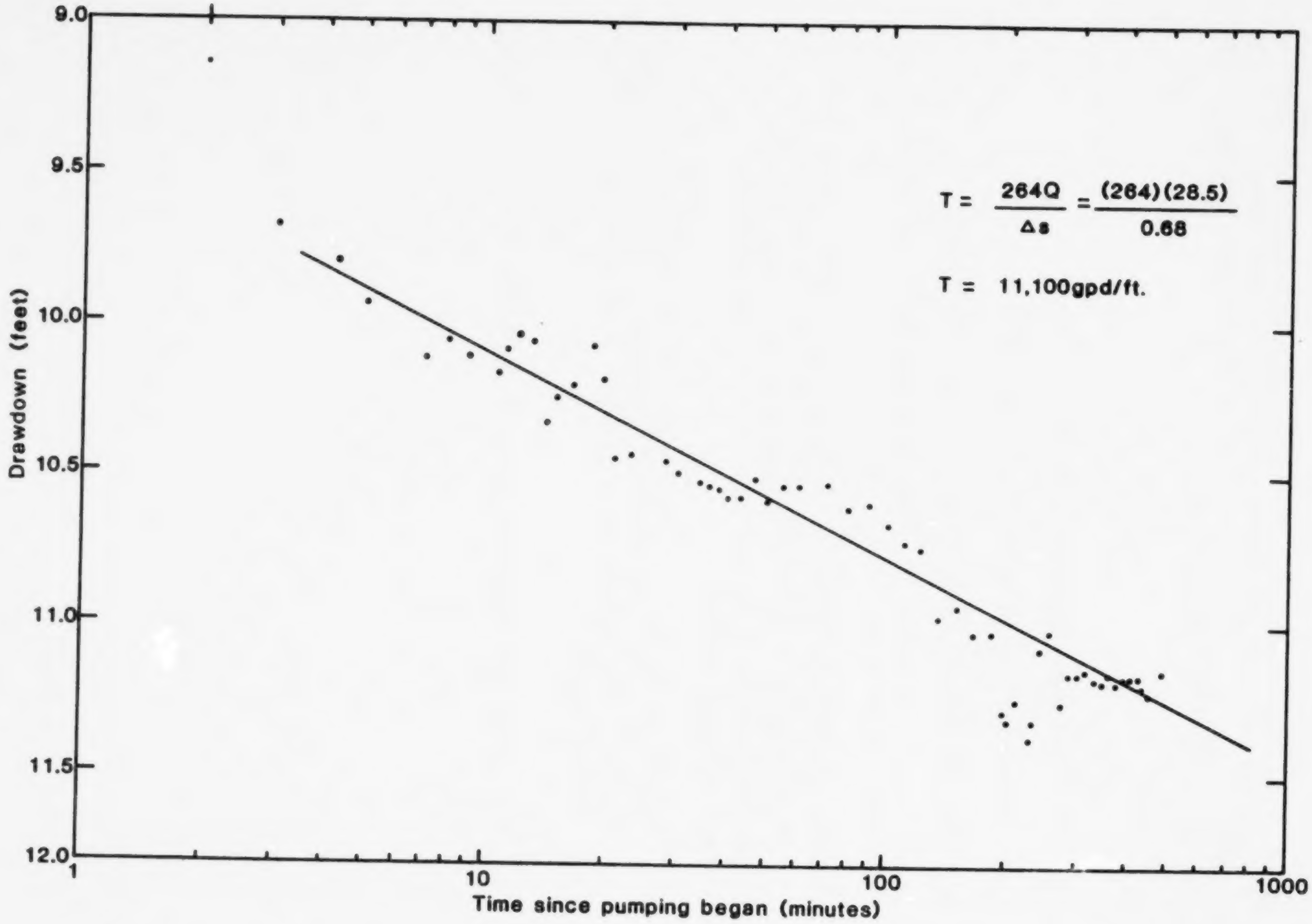

Figure C-1. Modified Theis nonequilibrium analysis using data from well K3D2.

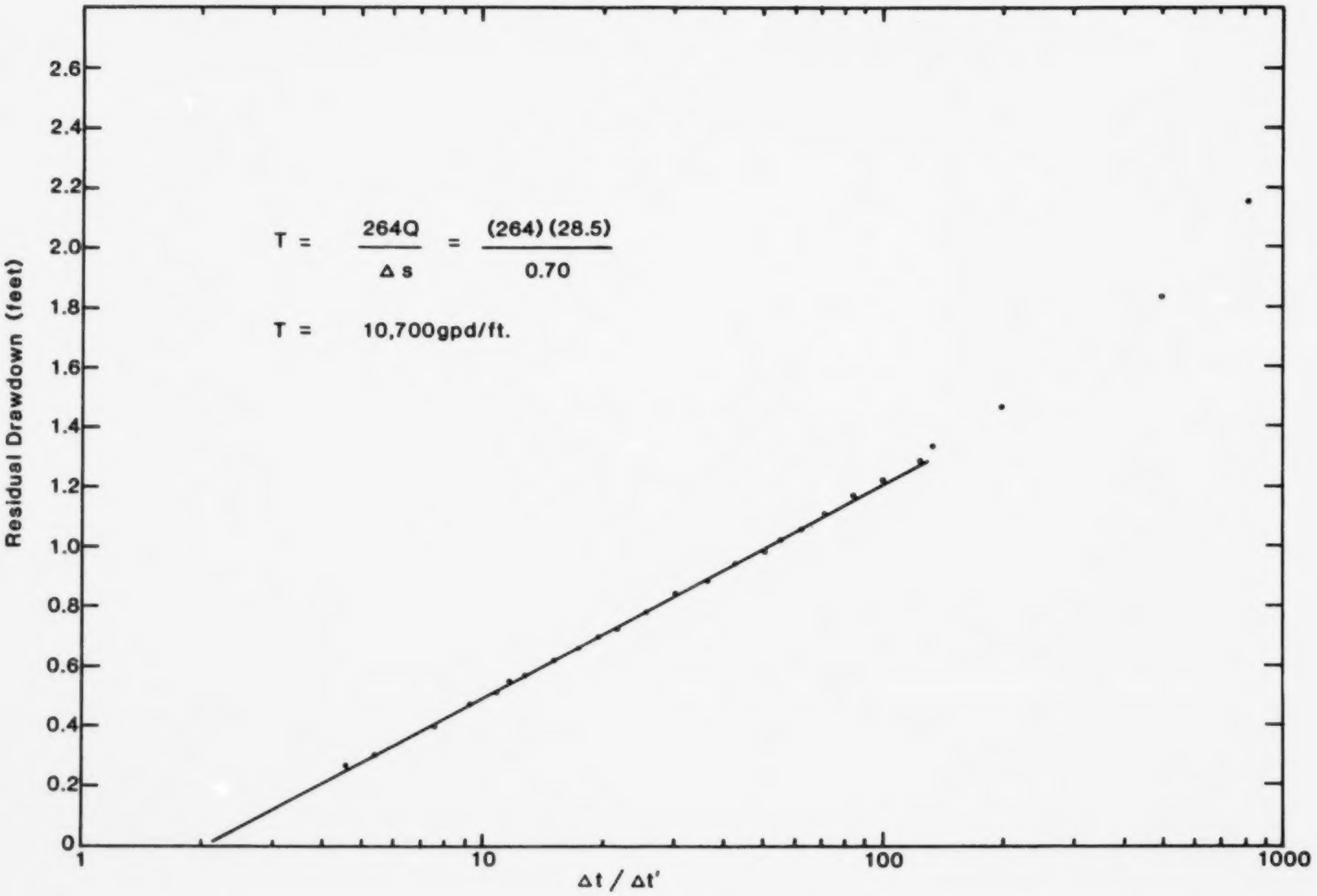

Figure C-2. Theis recovery analysis using data from well K3D2.

SECTION 2

AQUIFER PUMPING TEST
AT
PINE KNOLL SHORES

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AQUIFER PUMPING TEST AT PINE KNOLL SHORES, NC

An 8-hour aquifer pumping test was performed on 4 August 1984 in Pine Knoll Shores, NC. Pumping began at 0630 Eastern Daylight Time (EDT) and lasted until 1430 EDT. Well P2C2 was the pumped well. The average pumping rate from the well was 20.2 gallons per minute (gpm). The pumped water was discharged to the ground surface approximately 300 feet north of the well. Wells P2C1, P2C3 and P2C4 were used as observation wells.

Well construction details for the pumped well and the observation wells varied between wells. Well P2C1 is completed in unconsolidated sand deposits near the water-table surface. There is a two to three foot thick layer of organic silt material that starts about one-half foot below the base of this well. Well P2C3 is completed in unconsolidated sand deposits about five feet above the top of a soft clay layer whose thickness is approximately 13 feet. Well P2C2 is completed in unconsolidated sand deposits between the soft clay layer and the silt material. Well P2C4 is completed below the base of the soft clay layer. Construction details for the wells are summarized in Table 1. A cross-section showing the lithology at the site and the spacial relationship between wells is given in Figure 1.

Water levels were measured in the pumped well and each of the observation wells. Water level declines were observed in the pumped well and in observation wells P2C1 and P2C3. The water level in observation well P2C4 rose slightly during the pumping period. The observed water levels and computed water level changes during pumping are presented at the end of this section.

The computed transmissivity and hydraulic conductivity for the unconsolidated deposits are 15,800 gallons per day per foot (gpd/ft) and 445 gallons per day per foot squared (gpd/ft^2). The aquifer thickness used for the hydraulic conductivity computation was 35.5 feet. This thickness represents that from the water table, approximately 5.5 feet below land surface, to the top of the soft clay layer, approximately 41 feet below land surface.

The transmissivity of the unconsolidated deposits was computed using data collected from the pumped well and from observation well P2C3. The modified Theis nonequilibrium analysis (Ferris et al., 1962) and the Theis recovery analysis (Ferris et al., 1962), together with water level data for the pumped well and from observation well P2C3, were used to compute the transmissivity of the unconsolidated deposits.

The storage coefficient for the unconsolidated deposits was computed to be 0.00045. This property of the unconsolidated deposits was computed using the modified Theis nonequilibrium analysis and water level data collected from observation well P2C3.

The aquifer pumping test analysis is presented at the end of this section.

TABLE 1

WELL CONSTRUCTION SUMMARY

Well number	Well depth (feet)	Well diameter (inches)	Top of open interval below land surface (feet)	Screen length (feet)
P2C1	10.6	6	5.6	5.0
P2C2	30.0	4	15.0	15.0
P2C3	37.0	2	32.0	5.0
P2C4	69.5	2	64.5	5.0

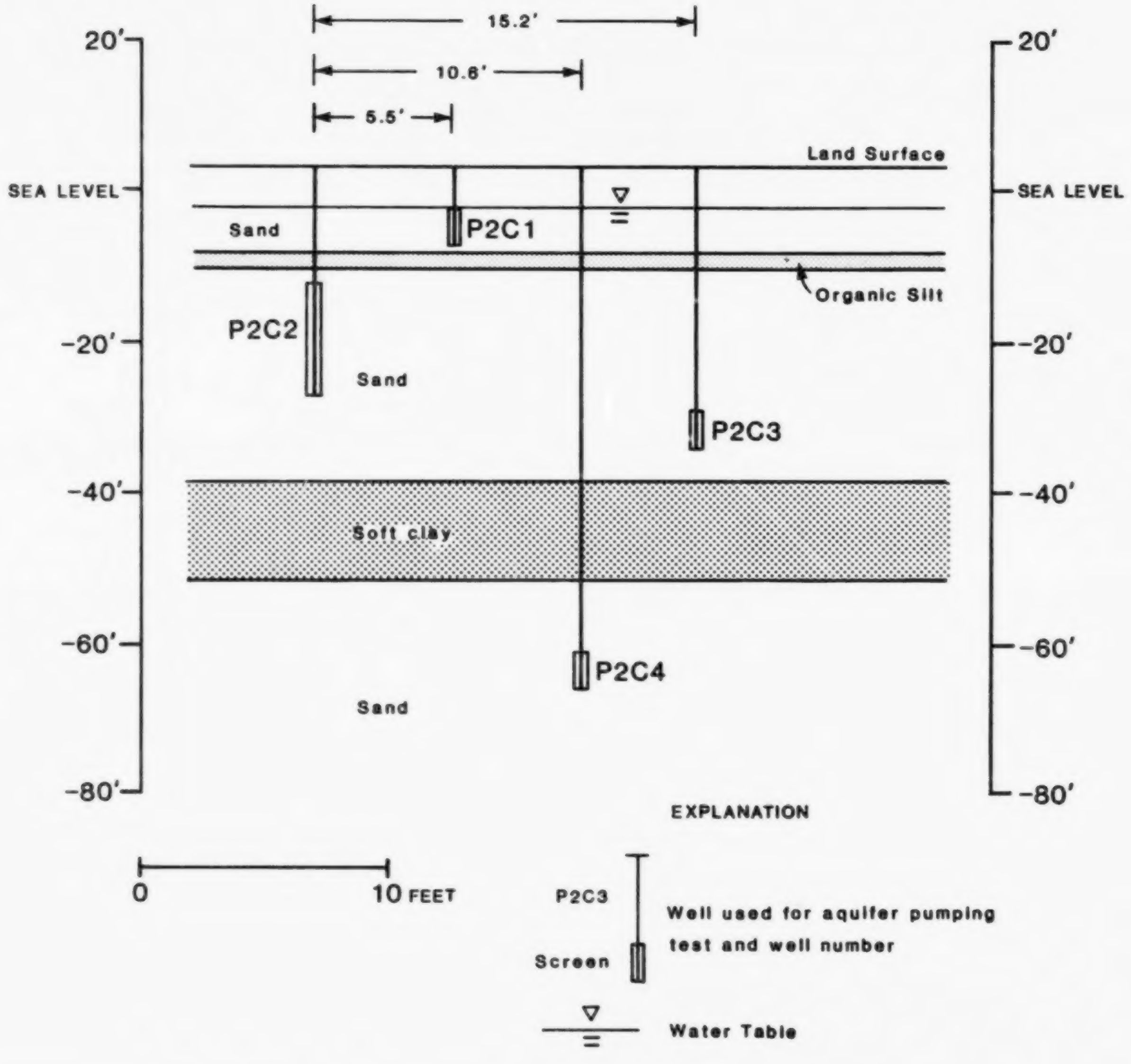

15.2'
10.6'
5.5'
20'
20'
Land Surface
SEA LEVEL
SEA LEVEL
Sand
P2C1
Organic Silt
P2C2
-20'
-20'
Sand
P2C3
-40'
-40'
Soft clay
-60'
-60'
P2C4
Sand
-80'
-80'
EXPLANATION
0
10 FEET
P2C3
Well used for aquifer pumping test and well number
Screen
Water Table

Figure 1. Geologic cross-section in vicinity of aquifer pump test site at Pine Knoll Shores, N.C.

The data collected at observation well P2C1 were not used for determining the hydraulic properties of the unconsolidated deposits. A preliminary analysis using the water level data from this observation well indicated that drawdowns in the well were influenced by the presence of the organic silt layer that lies between the open intervals for the pumped well and the observation well.

The slight rise in water levels observed in observation well P2C4 during the aquifer pumping test suggests that the unconsolidated deposits that lie below the soft clay layer are hydraulically separated from those that lie above this layer. This well is completed in the unconsolidated deposits below the soft clay layer. The data collected at well P2C4, although qualitatively very informative, could not be used for any type of quantitative analyses.

REFERENCES

Ferris, J.B. et al., 1962. Theory of aquifer tests: United States Geological Survey Water-Supply Paper 1536-E.

WATER LEVELS FOR AQUIFER PUMPING TEST

Water levels were recorded for the pumped well (Well P2C2) and for wells P2C1, P2C3 and P2C4 during the aquifer pumping test. These data are tabulated by well number in the tables which follow. In these tables, the column headings have the following meaning:

Date:	Date of reading.
Time:	Time of reading, Eastern Daylight Time (EDT).
Depth to water:	The depth to water below the measuring point, in feet.
Flow meter reading: (pumped well only)	The total gallons of flow recorded by the flow meter. The meter reading was 184.1 gallons prior to beginning the test.
Remarks:	Any pertinent remarks.

TABLE A1

WATER LEVEL AND PUMPING DATA FOR WELL P2C2

Date (1984)	Time (EDT)	Depth to water (feet)	Flow meter reading (gallons)	Remarks
August 4	0607	5.13		
	0615	5.13		
	0620	5.12		
	0629:30	5.12		
	0630		184.1	Pump on
	0630:14	8.00		
	0630:24	10.00		
	0630:30	10.61		
	0630:45	11.23		
	0631	11.45		Measure 20.7 gpm using flow meter
	0631:15	11.57		
	0631:30	11.61		
	0631:45	11.68		
	0632	11.71		
	0633	11.78		
	0634	11.81		Measure 20.6 gpm using flow meter
	0635	11.84		
	0636	11.84		
	0638	11.86		
	0640	11.89		Measure 20.7 gpm using flow meter
	0643		450	
	0645	11.92		
	0650	11.95		
	0655	11.97		
	0656			Measure 20.4 gpm using flow meter
	0657		740	
	0700	11.99		
	0707			Measure 20.5 gpm using flow meter
	0710	12.02		
	0715		1100	Measure 20.5 gpm using flow meter
	0720	12.05		
	0730	12.07		
	0746	12.10		
	0749			Measure 20.4 gpm using flow meter
	0750		1830	
	0800	12.13		
	0813			Measure 20.3 gpm using flow meter
	0815	12.15		
	0819		2400	
	0830	12.18		
	0845	12.18		
	0848		3000	
	0850			Measure 20.3 gpm using flow meter
	0900	12.21		
	0915	12.24		
	0918		3610	
	0920			Measure 20.3 gpm using flow meter
	0930	12.24		
	0933			Measure 20.3 gpm using flow meter
	0934		3930	
	0945	12.26		
	1000	12.27		
	1003		4520	Measure 20.3 gpm using flow meter
	1015	12.28		
	1017		4800	Measure 20.2 gpm using flow meter
	1030	12.31		
	1032		5100	
	1033			Measure 20.3 gpm using flow meter
	1100	12.33		
	1102		5710	
	1103			Measure 20.2 gpm using flow meter
	1131	12.31		
	1137		6410	Measure 20.2 gpm using flow meter
	1200	12.37		

TABLE A1
(continued)
WATER LEVEL AND PUMPING DATA FOR WELL P2C2

Date (1984)	Time (EDT)	Depth to water (feet)	Flow meter reading (gallons)	Remarks
August 4	1203		6930	
(continued)	1205			Measure 20.2 gpm using flow meter
	1234	12.40		
	1237		7630	
	1238			Measure 20.1 gpm using flow meter
	1300	12.40		
	1303		8140	
	1305			Measure 20.1 gpm using flow meter
	1330	12.44		
	1333		8750	
	1334			Measure 20.2 gpm using flow meter
	1400	12.45		
	1403		9350	
	1404			Measure 20.1 gpm using flow meter
	1429	12.48		
	1430		9896.6	Pump off
	1430:07	10.00		
	1430:15	8.00		
	1430:30	6.62		
	1431	6.00		
	1431:30	5.85		
	1432	5.80		
	1433	5.75		
	1434	5.72		
	1435	5.71		
	1436	5.69		
	1437	5.69		
	1438:30	5.68		
	1441	5.70		
	1443	5.69		
	1445	5.64		
	1448	5.64		
	1450	5.64		
	1453	5.63		
	1455	5.62		
	1458	5.61		
	1500	5.61		
	1504	5.60		
	1508	5.59		
	1515	5.58		
	1520	5.55		
	1530	5.55		
	1540	5.54		
	1550	5.54		
	1600	5.51		
	1615	5.51		
	1630	5.49		
	1707	5.47		
	1732	5.45		
	1801	5.54		
	1827	5.45		
	1909	5.41		
	1941	5.41		
August 5	1025	5.30		

Total gallons pumped is 9,712.5 gallons
Average pumping rate is 20.2 gpm

TABLE A2

WATER LEVEL DATA FOR OBSERVATION WELL P2C1

Date (1984)	Time (EDT)	Depth to water (feet)	Remarks
August 4	0605	6.31	
	0619	6.32	
	0630		Pump on
	0632:30	6.56	
	0634:30	6.63	
	0637	6.68	
	0642	6.70	
	0648	6.76	
	0653	6.80	
	0658	6.83	
	0708	6.89	
	0718	6.94	
	0731	6.99	
	0744	7.02	
	0801	7.07	
	0814	7.10	
	0829	7.12	
	0844	7.14	
	0859	7.17	
	0914	7.18	
	0929	7.21	
	0959	7.23	
	1014	7.25	
	1029	7.28	
	1058	7.31	
	1132	7.35	
	1159	7.38	
	1233	7.43	
	1259	7.43	
	1329	7.45	
	1359	7.47	
	1426	7.49	
	1430		Pump off
	1433:30	7.23	
	1435:30	7.20	
	1437:30	7.18	
	1439	7.15	
	1442	7.15	
	1446	7.09	
	1451	7.06	
	1456	7.04	
	1501	7.03	
	1508	7.00	
	1514	6.98	
	1519	6.96	
	1529	6.92	
	1539	6.91	
	1549	6.87	
	1559	6.87	
	1614	6.83	
	1632	6.82	
	1706	6.79	
	1736	6.75	
	1805	6.74	
	1910	6.69	
	1934	6.68	
August 5	1023	6.55	

TABLE A3

WATER LEVEL DATA FOR OBSERVATION WELL P2C3

Date (1984)	Time (EDT)	Depth to water (feet)	Remarks
August 4	0608	4.87	
	0621	4.86	
	0630		Pump on
	0633:30	5.98	
	0635:30	6.04	
	0639	6.09	
	0644	6.12	
	0649	6.14	
	0654	6.14	
	0659	6.18	
	0709	6.19	
	0721	6.23	
	0732	6.24	
	0745	6.24	
	0802	6.30	
	0816	6.32	
	0831	6.32	
	0846	6.35	
	0901	6.37	
	0916	6.38	
	0931	6.40	
	0946	6.42	
	1001	6.43	
	1016	6.44	
	1031	6.47	
	1059	6.48	
	1133	6.49	
	1202	6.50	
	1235	6.53	
	1301	6.56	
	1331	6.57	
	1401	6.53	
	1427	6.60	
	1430		Pump off
	1432:30	5.61	
	1434:30	5.46	
	1436:30	5.42	
	1438	5.41	
	1444	5.38	
	1447	5.36	
	1452	5.35	
	1457	5.33	
	1459	5.34	
	1502	5.32	
	1511	5.31	
	1516	5.30	
	1521	5.25	
	1531	5.28	
	1533	5.28	
	1541	5.27	
	1551	5.26	
	1601	5.24	
	1616	5.23	
	1631	5.22	
	1708	5.20	
	1733	5.19	
	1802	5.17	
	1828	5.17	
	1908	5.15	
	1932	5.14	
August 5	1026	5.04	

TABLE A4

WATER LEVEL DATA FOR OBSERVATION WELL P2C4

Date (1984)	Time (EDT)	Depth to water (feet)	Remarks
August 4	0610	5.59	
	0622	5.59	
	0630		Pump on
	0641	5.58	
	0651	5.56	
	0711	5.53	
	0722	5.52	
	0733	5.52	
	0747	5.52	
	0803	5.52	
	0817	5.53	
	0847	5.52	
	0917	5.52	
	0932	5.52	
	0947	5.52	
	1002	5.52	
	1032	5.52	
	1101	5.52	
	1134	5.51	
	1202	5.52	
	1236	5.52	
	1332	5.51	
	1428	5.51	
	1430		Pump off
	1440	5.51	
	1449	5.51	
	1454	5.52	
	1503	5.52	
	1517	5.52	
	1532	5.52	
	1602	5.52	
	1633	5.53	
	1709	5.52	
	1734	5.53	
	1803	5.53	
	1907	5.54	
August 5	1027	5.56	

DRAWDOWN COMPUTATIONS FOR AQUIFER PUMPING TEST

Drawdowns in the pumped well and in the observation wells during the aquifer pumping test were computed based on the water-level observations. The drawdown computations for these wells are tabulated in the tables which follow. In these tables, the column headings have the following meaning:

Date:	Date of reading.
Time:	Time of reading, Eastern Daylight Time (EDT).
Δt:	Time from start of pumping, in minutes.
$\Delta t'$:	Time since pumping stopped, in minutes.
Depth to water:	Depth to water below the measuring point, in feet.
Trend Corr.:	A correction to account for the natural trend in water levels. The correction is based on the observed water level trend in well P2C1 during the period August 6-20, 1984.
s:	Drawdown in the well, in feet. Drawdown is computed by adding the trend correction to the depth to water measurement and substracting from this total the depth to water measured at approximately 0620 EDT on August 4, 1984.
$s^2/2M$:	A correction to account for dewatering of the aquifer system, in feet. The saturated thickness of the aquifer system in the vicinity of the well prior to pumping is represented by M. For these computations the value for M is 35.5 feet.
s':	The drawdown in the well corrected for the effects of dewatering, in feet. This drawdown is termed residual drawdown whenever $\Delta t'$ is greater than zero.
Remarks:	Any pertinent remarks.

TABLE B1

DRAWDOWN COMPUTATIONS FOR WELL P2C2

Date (1984)	Time (EDT)	Δt (min)	Δt' (min)	$\frac{\Delta t}{\Delta t}$	Depth to water (feet)	Trend corr. (feet)	s (feet)	$\frac{s^2}{2H}$ (feet)	s' (feet)	Remarks
August 4	0629:30				5.12					Assume static water level
	0630									Pump on
	0630:14	0.23			8.00	0	2.88	0.12	2.76	
	0630:24	0.40			10.00	0	4.88	0.34	4.54	
	0630:30	0.50			10.61	0	5.49	0.42	5.07	
	0630:45	0.75			11.23	0	6.11	0.53	5.58	
	0631	1.0			11.45	0	6.33	0.56	5.77	
	0631:15	1.25			11.57	0	6.45	0.59	5.86	
	0631:30	1.50			11.61	0	6.49	0.59	5.90	
	0631:45	1.75			11.68	0	6.56	0.61	5.95	
	0632	2.0			11.71	0	6.59	0.61	5.98	
	0633	3.0			11.78	0	6.66	0.62	6.04	
	0634	4.0			11.81	0	6.69	0.63	6.06	
	0635	5.0			11.84	0	6.72	0.64	6.08	
	0636	6.0			11.84	0	6.72	0.64	6.08	
	0638	8.0			11.86	0	6.74	0.64	6.10	
	0640	10			11.89	0	6.77	0.65	6.12	
	0645	15			11.92	0	6.80	0.65	6.15	
	0650	20			11.95	0	6.83	0.66	6.17	
	0655	25			11.97	0	6.85	0.66	6.19	
	0700	30			11.99	0	6.87	0.66	6.21	
	0710	40			12.02	0	6.90	0.67	6.23	
	0720	50			12.05	0	6.93	0.68	6.25	
	0730	60			12.07	0	6.95	0.68	6.27	
	0746	76			12.10	0	6.98	0.69	6.29	
	0800	90			12.13	-0.01	7.00	0.69	6.31	
	0815	105			12.15	-0.01	7.02	0.69	6.33	
	0830	120			12.18	-0.01	7.05	0.70	6.35	
	0845	135			12.18	-0.01	7.05	0.70	6.35	
	0900	150			12.21	-0.01	7.08	0.71	6.37	
	0915	165			12.24	-0.01	7.11	0.71	6.40	
	0930	180			12.24	-0.01	7.11	0.71	6.40	
	0945	195			12.26	-0.01	7.13	0.72	6.41	
	1000	210			12.27	-0.01	7.14	0.72	6.42	
	1015	225			12.28	-0.01	7.15	0.72	6.43	
	1030	240			12.31	-0.01	7.18	0.73	6.45	
	1100	270			12.33	-0.01	7.20	0.73	6.47	
	1131	301			12.31	-0.01	7.18	0.73	6.45	
	1200	330			12.37	-0.01	7.24	0.74	6.50	
	1234	364			12.40	-0.02	7.26	0.74	6.52	
	1300	390			12.40	-0.02	7.26	0.74	6.52	
	1330	420			12.44	-0.02	7.30	0.75	6.55	
	1400	450			12.45	-0.02	7.31	0.75	6.56	
	1429	479			12.48	-0.02	7.34	0.76	6.58	
	1430	480								Pump off

TABLE B1
(continued)
DRAWDOWN COMPUTATIONS FOR WELL P2C2

Date (1984)	Time (EDT)	Δt (min)	Δt' (min)	$\frac{\Delta t}{\Delta t}$	Depth to water (feet)	Trend corr. (feet)	s (feet)	$\frac{s^2}{2H}$ (feet)	s' (feet)	Remarks
August 4 (continued)	1430:07	480.1	0.12	4001	10.00	-0.02	4.86	0.33	4.53	
	1430:15	480.2	0.25	1921	8.00	-0.02	2.86	0.12	2.74	
	1430:30	480.5	0.50	961	6.62	-0.02	1.48	0.03	1.45	
	1431	481	1.0	481	6.00	-0.02	0.86	0.01	0.85	
	1431:30	481.5	1.5	321	5.85	-0.02	0.71	0.01	0.70	
	1432	482	2.0	241	5.80	-0.02	0.66	0.01	0.65	
	1433	483	3.0	161	5.75	-0.02	0.61	0	0.61	
	1434	484	4.0	121	5.72	-0.02	0.58	0	0.58	
	1435	485	5.0	97.0	5.71	-0.02	0.57	0	0.57	
	1436	486	6.0	81.0	5.69	-0.02	0.55	0	0.55	
	1437	487	7.0	69.6	5.69	-0.02	0.55	0	0.55	
	1438:30	488.5	8.5	57.5	5.68	-0.02	0.54	0	0.54	
	1441	491	11	44.6	5.70	-0.02	0.56	0	0.56	
	1443	493	13	37.9	5.69	-0.02	0.55	0	0.55	
	1445	495	15	33.0	5.64	-0.02	0.50	0	0.50	
	1448	498	18	27.7	5.64	-0.02	0.50	0	0.50	
	1450	500	20	25.0	5.64	-0.02	0.50	0	0.50	
	1453	503	23	21.9	5.63	-0.02	0.49	0	0.49	
	1455	505	25	20.2	5.62	-0.02	0.48	0	0.48	
	1458	508	28	18.1	5.61	-0.02	0.47	0	0.47	
	1500	510	30	17.0	5.61	-0.02	0.47	0	0.47	
	1504	514	34	15.1	5.60	-0.02	0.46	0	0.46	
	1508	518	38	13.6	5.59	-0.02	0.45	0	0.45	
	1515	525	45	11.7	5.58	-0.02	0.44	0	0.44	
	1520	530	50	10.6	5.55	-0.02	0.41	0	0.41	
	1530	540	60	9.00	5.55	-0.02	0.41	0	0.41	
	1540	550	70	7.86	5.54	-0.02	0.40	0	0.40	
	1550	560	80	7.00	5.54	-0.02	0.40	0	0.40	
	1600	570	90	6.33	5.51	-0.03	0.36	0	0.36	
	1615	585	105	5.57	5.51	-0.03	0.36	0	0.36	
	1630	600	120	5.00	5.49	-0.03	0.34	0	0.34	
	1707	637	157	4.06	5.47	-0.03	0.32	0	0.32	
	1732	662	182	3.64	5.45	-0.03	0.30	0	0.30	
	1801	691	211	3.27	5.54	-0.03	0.39	0	0.39	
	1827	717	237	3.03	5.45	-0.03	0.30	0	0.30	
	1909	759	279	2.72	5.41	-0.03	0.26	0	0.26	
	1941	791	311	2.54	5.41	-0.03	0.26	0	0.26	
August 5	1025	1675	1195	1.40	5.30	-0.07	0.11	0	0.11	

TABLE B2

DRAWDOWN COMPUTATIONS FOR WELL P2C1

Date (1984)	Time (EDT)	Δt (min)	Δt' (min)	$\frac{\Delta t}{\Delta t}$	Depth to water (feet)	Trend corr. (feet)	s (feet)	$\frac{s^2}{2H}$ (feet)	s' (feet)	Remarks
August 4	0619				6.32					Assume static water level
	0630									Pump on
	0632:30	2.5			6.56	0	0.24	0	0.24	
	0634:30	4.5			6.63	0	0.31	0	0.31	
	0637	7.0			6.68	0	0.36	0	0.36	
	0642	12			6.70	0	0.38	0	0.38	
	0648	18			6.76	0	0.44	0	0.44	
	0653	23			6.80	0	0.48	0	0.48	
	0658	28			6.83	0	0.51	0	0.51	
	0708	38			6.89	0	0.57	0	0.57	
	0718	48			6.94	0	0.62	0.01	0.61	
	0731	61			6.99	0	0.67	0.01	0.66	
	0744	74			7.02	0	0.70	0.01	0.69	
	0801	91			7.07	-0.01	0.74	0.01	0.73	
	0814	104			7.10	-0.01	0.77	0.01	0.76	
	0829	119			7.12	-0.01	0.79	0.01	0.78	
	0844	134			7.14	-0.01	0.81	0.01	0.80	
	0859	149			7.17	-0.01	0.84	0.01	0.83	
	0914	164			7.18	-0.01	0.85	0.01	0.84	
	0929	179			7.21	-0.01	0.88	0.01	0.87	
	0959	209			7.23	-0.01	0.90	0.01	0.89	
	1014	224			7.25	-0.01	0.92	0.01	0.91	
	1029	239			7.28	-0.01	0.95	0.01	0.94	
	1058	268			7.31	-0.01	0.98	0.01	0.97	
	1132	302			7.35	-0.01	1.02	0.01	1.01	
	1159	329			7.38	-0.01	1.05	0.02	1.03	
	1233	363			7.43	-0.02	1.09	0.02	1.07	
	1259	389			7.43	-0.02	1.09	0.02	1.07	
	1329	419			7.45	-0.02	1.11	0.02	1.09	
	1359	449			7.47	-0.02	1.13	0.02	1.11	
	1426	476			7.49	-0.02	1.15	0.02	1.13	
	1430	480								Pump off
	1433:30	483.5	3.5	138	7.23	-0.02	0.89	0.01	0.88	
	1435:30	485.5	5.5	88.3	7.20	-0.02	0.86	0.01	0.85	
	1437:30	487.5	7.5	65.0	7.18	-0.02	0.84	0.01	0.83	
	1439	489	9.5	51.5	7.15	-0.02	0.81	0.01	0.80	
	1442	492	12	41.0	7.15	-0.02	0.81	0.01	0.80	
	1446	496	16	31.0	7.09	-0.02	0.75	0.01	0.74	
	1451	501	21	23.9	7.06	-0.02	0.72	0.01	0.71	
	1456	506	26	19.5	7.04	-0.02	0.70	0.01	0.69	
	1501	511	31	16.5	7.03	-0.02	0.69	0.01	0.68	
	1508	518	38	13.6	7.00	-0.02	0.66	0.01	0.65	
	1514	524	44	11.9	6.98	-0.02	0.64	0.01	0.63	
	1519	529	49	10.8	6.96	-0.02	0.62	0.01	0.61	

TABLE B2
(continued)
DRAWDOWN COMPUTATIONS FOR WELL P2C1

Date (1984)	Time (EDT)	Δt (min)	Δt' (min)	$\frac{\Delta t}{\Delta t}$	Depth to water (feet)	Trend corr. (feet)	s (feet)	$\frac{s^2}{2H}$ (feet)	s' (feet)	Remarks
August 4	1529	539	59	9.14	6.92	-0.02	0.58	0	0.58	
(continued)	1539	549	69	7.96	6.91	-0.02	0.57	0	0.57	
	1549	559	79	7.08	6.87	-0.02	0.53	0	0.53	
	1559	569	89	6.39	6.87	-0.02	0.53	0	0.53	
	1614	584	104	5.62	6.83	-0.03	0.48	0	0.48	
	1632	602	122	4.93	6.82	-0.03	0.47	0	0.47	
	1706	636	156	4.08	6.79	-0.03	0.44	0	0.44	
	1736	666	186	3.58	6.75	-0.03	0.40	0	0.40	
	1805	695	215	3.23	6.74	-0.03	0.39	0	0.39	
	1910	760	280	2.71	6.69	-0.03	0.34	0	0.34	
	1934	784	304	2.58	6.68	-0.03	0.33	0	0.33	
August 5	1023	1673	1193	1.40	6.55	-0.07	0.16	0	0.16	

TABLE B3

DRAWDOWN COMPUTATIONS FOR WELL P2C3

Date (1984)	Time (EDT)	Δt (min)	Δt' (min)	$\frac{\Delta t}{\Delta t}$	Depth to water (feet)	Trend corr. (feet)	s (feet)	$\frac{s^2}{2H}$ (feet)	s' (feet)	Remarks
August 4	0621				4.86					Assume static water level
	0630									Pump on
	0633:30	3.5			5.98	0	1.12	0.02	1.10	
	0635:30	5.5			6.04	0	1.18	0.02	1.16	
	0639	9.0			6.09	0	1.23	0.02	1.21	
	0644	14			6.12	0	1.26	0.02	1.24	
	0649	19			6.14	0	1.28	0.02	1.26	
	0654	24			6.14	0	1.28	0.02	1.26	
	0659	29			6.18	0	1.32	0.02	1.30	
	0709	39			6.19	0	1.33	0.02	1.31	
	0721	51			6.23	0	1.37	0.03	1.34	
	0732	62			6.24	0	1.38	0.03	1.35	
	0745	75			6.24	0	1.38	0.03	1.35	
	0802	92			6.30	-0.01	1.43	0.03	1.40	
	0816	106			6.32	-0.01	1.45	0.03	1.42	
	0831	121			6.32	-0.01	1.45	0.03	1.42	
	0846	136			6.35	-0.01	1.48	0.03	1.45	
	0901	151			6.37	-0.01	1.50	0.03	1.47	
	0916	166			6.38	-0.01	1.51	0.03	1.48	
	0931	181			6.40	-0.01	1.53	0.03	1.50	
	0946	196			6.42	-0.01	1.55	0.03	1.52	
	1001	211			6.43	-0.01	1.56	0.03	1.53	
	1016	226			6.44	-0.01	1.57	0.03	1.54	
	1031	241			6.47	-0.01	1.60	0.04	1.56	
	1059	269			6.48	-0.01	1.61	0.04	1.57	
	1133	303			6.49	-0.01	1.62	0.04	1.58	
	1202	332			6.50	-0.02	1.62	0.04	1.58	
	1235	365			6.53	-0.02	1.65	0.04	1.61	
	1301	391			6.56	-0.02	1.68	0.04	1.64	
	1331	421			6.57	-0.02	1.69	0.04	1.65	
	1401	451			6.53	-0.02	1.65	0.04	1.61	
	1427	477			6.60	-0.02	1.72	0.04	1.68	
	1430	480								Pump off
	1432:30	482.5	2.5	193	5.61	-0.02	0.73	0.01	0.72	
	1434:30	484.5	4.5	108	5.46	-0.02	0.58	0	0.58	
	1436:30	486.5	6.5	74.8	5.42	-0.02	0.54	0	0.54	
	1438	488	8.0	61.0	5.41	-0.02	0.53	0	0.53	
	1444	494	14	35.3	5.38	-0.02	0.50	0	0.50	
	1447	497	17	29.2	5.36	-0.02	0.48	0	0.48	
	1452	502	22	22.8	5.35	-0.02	0.47	0	0.47	
	1457	507	27	18.8	5.33	-0.02	0.45	0	0.45	
	1459	509	29	17.6	5.34	-0.02	0.46	0	0.46	
	1502	512	32	16.0	5.32	-0.02	0.44	0	0.44	
	1511	521	41	12.7	5.31	-0.02	0.43	0	0.43	
	1516	526	46	11.4	5.30	-0.02	0.42	0	0.42	

TABLE B3
(continued)
DRAWDOWN COMPUTATIONS FOR WELL P2C3

Date (1984)	Time (EDT)	Δt (min)	$\Delta t'$ (min)	$\frac{\Delta t}{\Delta t'}$	Depth to water (feet)	Trend corr. (feet)	s (feet)	$\frac{s^2}{2H}$ (feet)	s' (feet)	Remarks
August 4 (continued)	1521	531	51	10.4	5.25	-0.02	0.37	0	0.37	
	1531	541	61	8.87	5.28	-0.02	0.40	0	0.40	
	1533	543	63	8.62	5.28	-0.02	0.40	0	0.40	
	1541	551	71	7.76	5.27	-0.02	0.39	0	0.39	
	1551	561	81	6.93	5.26	-0.02	0.38	0	0.38	
	1601	571	91	6.27	5.24	-0.03	0.35	0	0.35	
	1616	586	106	5.53	5.23	-0.03	0.34	0	0.34	
	1631	601	121	4.97	5.22	-0.03	0.33	0	0.33	
	1708	638	158	4.04	5.20	-0.03	0.31	0	0.31	
	1733	663	183	3.62	5.19	-0.03	0.30	0	0.30	
	1802	692	212	3.26	5.17	-0.03	0.28	0	0.28	
	1828	718	238	3.02	5.17	-0.03	0.28	0	0.28	
	1908	758	278	2.73	5.15	-0.03	0.26	0	0.26	
	1932	782	302	2.59	5.14	-0.03	0.25	0	0.25	
August 5	1026	1676	1196	1.40	5.04	-0.07	0.11	0	0.11	

TABLE B4

DRAWDOWN COMPUTATIONS FOR WELL P2C4

Date (1984)	Time (EDT)	Δt (min)	Δt' (min)	Δt Δt	Depth to water (feet)	Trend corr. (feet)	s (feet)	Remarks
August 4	0610				5.59	0		
	0622				5.59	0		Assume static water level
	0630	0						Pump on
	0641	11			5.58	0	-0.01	
	0651	21			5.56	0	-0.03	
	0711	41			5.53	0	-0.06	
	0722	52			5.52	0	-0.07	
	0733	63			5.52	0	-0.07	
	0747	77			5.52	0	-0.07	
	0803	93			5.52	-0.01	-0.08	
	0817	107			5.53	-0.01	-0.09	
	0847	137			5.52	-0.01	-0.08	
	0917	167			5.52	-0.01	-0.08	
	0932	182			5.52	-0.01	-0.08	
	0947	197			5.52	-0.01	-0.08	
	1002	212			5.52	-0.01	-0.08	
	1032	242			5.52	-0.01	-0.08	
	1101	271			5.52	-0.01	-0.08	
	1134	304			5.51	-0.01	-0.09	
	1202	332			5.52	-0.01	-0.08	
	1236	366			5.52	-0.02	-0.09	
	1332	422			5.51	-0.02	-0.10	
	1428	478			5.51	-0.02	-0.10	
	1430	480						Pump off
	1440	490	10	49.0	5.51	-0.02	-0.10	
	1449	499	19	26.3	5.51	-0.02	-0.10	
	1454	504	24	21.0	5.52	-0.02	-0.09	
	1503	513	33	15.5	5.52	-0.02	-0.09	
	1517	527	47	11.2	5.52	-0.02	-0.09	
	1532	542	62	8.74	5.52	-0.02	-0.09	
	1602	572	92	6.22	5.52	-0.03	-0.10	
	1633	603	123	4.90	5.53	-0.03	-0.09	
	1709	639	159	4.02	5.52	-0.03	-0.10	
	1734	664	184	3.61	5.53	-0.03	-0.09	
	1803	693	213	3.25	5.53	-0.03	-0.09	
	1907	757	277	2.73	5.54	-0.03	-0.08	
August 5	1027	1677	1197	1.40	5.56	-0.07	-0.10	

AQUIFER PUMPING TEST ANALYSIS

Water level data for the pumped well and for observation well P2C3 were used to compute the hydraulic properties of the unconsolidated deposits. The modified Theis nonequilibrium analysis using water level data for the pumped well and observation well P2C3 were used to compute transmissivity. The Theis recovery analysis, together with water level recovery data for the pumped well and observation well P2C3, were also used to compute transmissivity. The storage coefficient was computed using the modified Theis nonequilibrium analysis and water level data for observation well P2C3.

Water level data collected during the latter part of testing were used to compute the hydraulic properties of the aquifer. The later data represent a sampling of the hydraulic properties of the shallow aquifer system over a larger area and are more representative of average conditions in the aquifer.

The behavior of the early drawdown and recovery data indicated that a barrier boundary was present in the vicinity of the pumped well. However, the lithologic data available from other boreholes in the vicinity of the test well strongly precluded the existence of any such boundary. The behavior of the observed data probably reflects the integrated effects of nonhomogeneity and anisotropy in the shallow aquifer over the area tested. A nonhomogeneous aquifer is one in which the hydraulic properties change spatially. A anisotropic aquifer is one whose horizontal hydraulic conductivity is different from its vertical hydraulic conductivity.

The modified Theis nonequilibrium analysis formula used for computing transmissivity is:

$$T = \frac{264Q}{\Delta s}$$

The variables in the above equation have the following meaning:

T = transmissivity, in gallons per day per foot;

Q = average pumping rate, in gallons per minute; and

Δs = change in drawdown over one log-cycle for a semi-log plot of time and drawdown.

The form of the Theis recovery analysis formula used for the transmissivity computation is the same as the form of the modified Theis nonequilibrium analysis formula used for this computation. However, for the Theis recovery analysis:

Δs = change in residual drawdown over one log-cycle for a semi-log plot of $\Delta t/\Delta t'$ and residual drawdown. Time since pumping began is defined by Δt and time since pumping stopped is defined by $\Delta t'$.

The modified Theis nonequilibrium analysis formula used for computing the storage coefficient is:

$$S = \frac{2.09 \times 10^{-4} T t_0}{r^2}$$

The variables in this equation that have not previously been defined have the following meanings:

S = storage coefficient, no dimensions;

t_0 = the time at which a straight line drawn through the data intercepts the zero drawdown line for a semi-log plot of time and drawdown, in minutes; and

r = distance from pumping well to observation well, in feet.

The data plots and data analyses are presented in Figures C1, C2, C3 and C4.

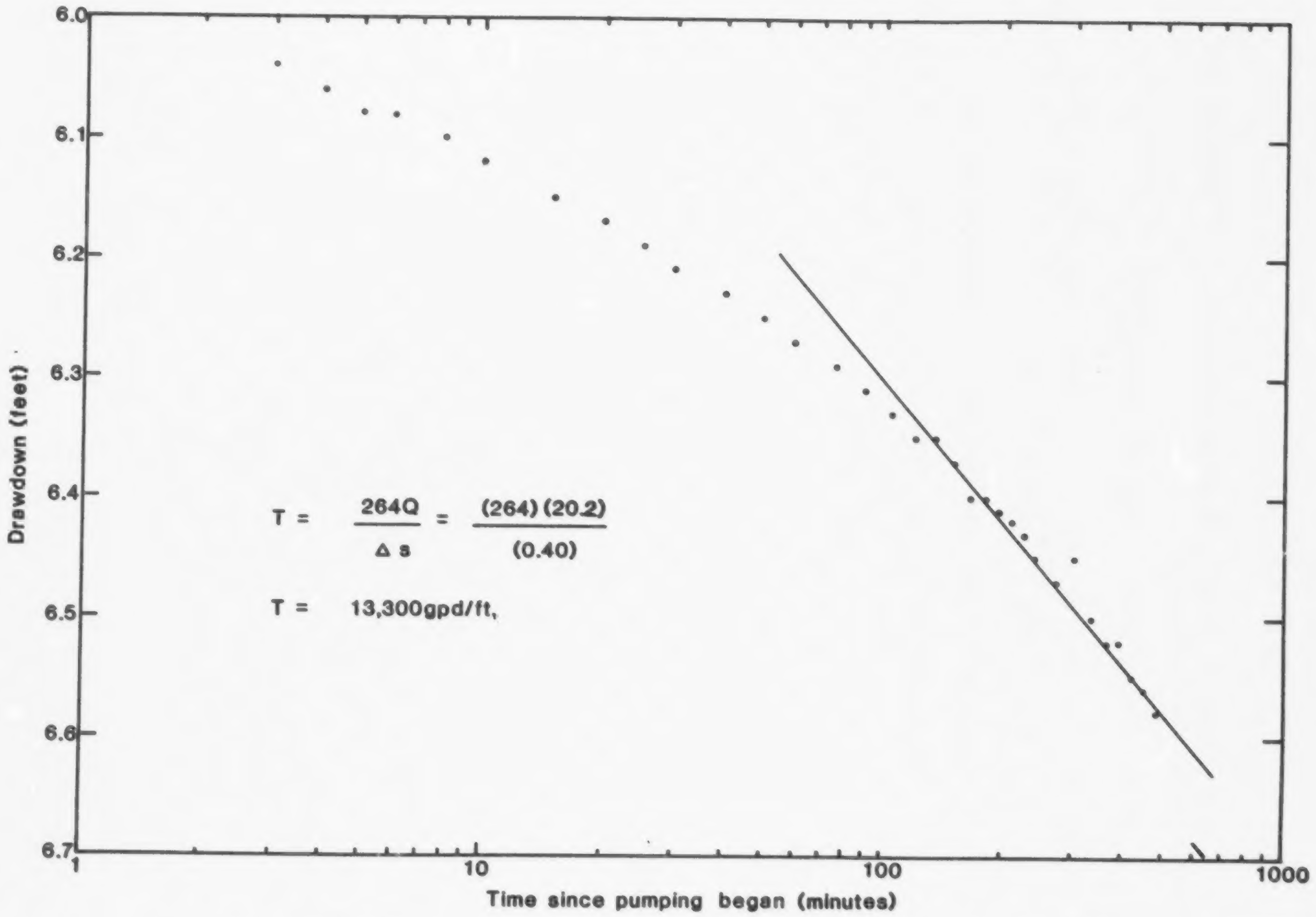


Figure C-1. Modified Theis nonequilibrium analysis using data from well P2C2.

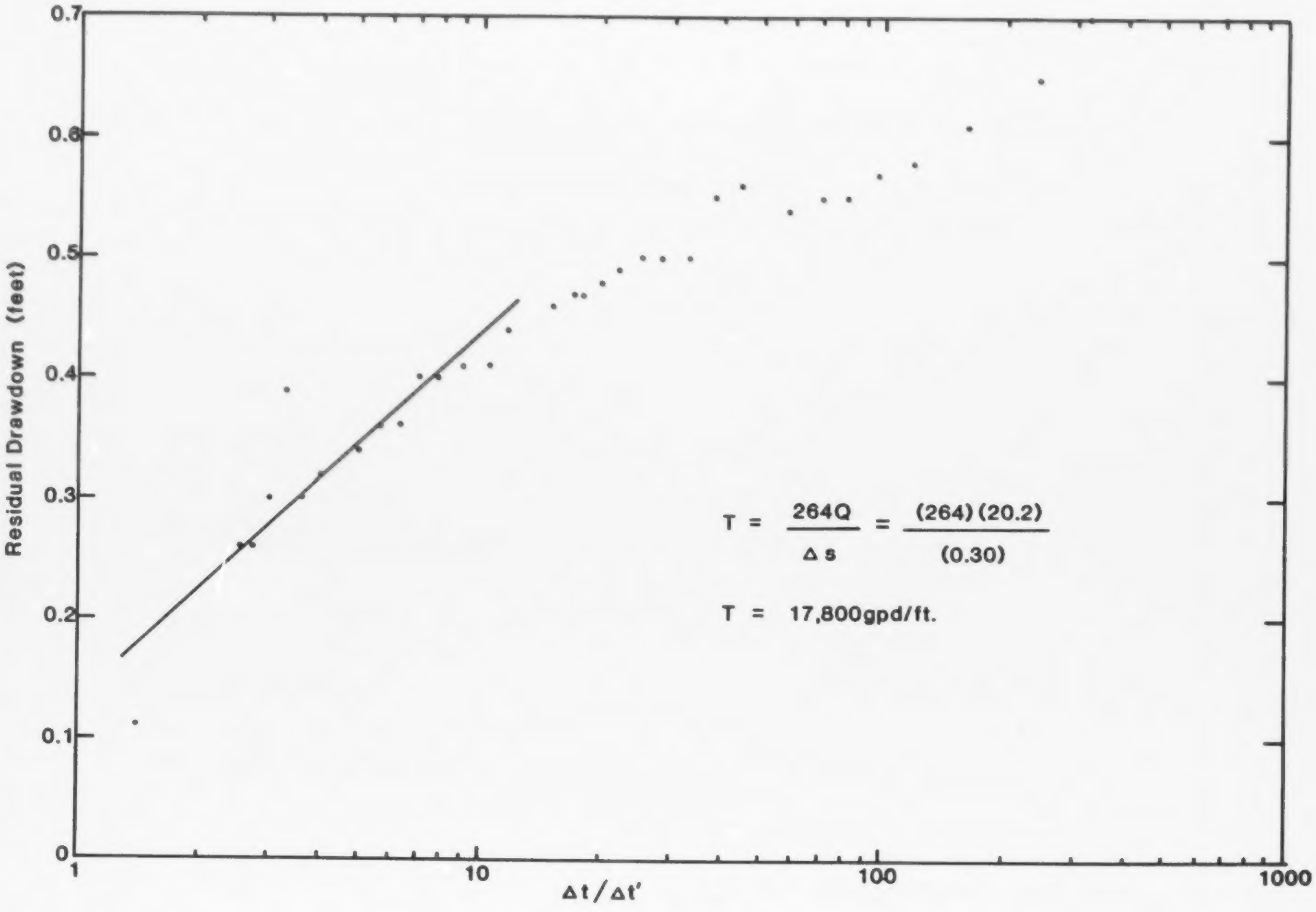
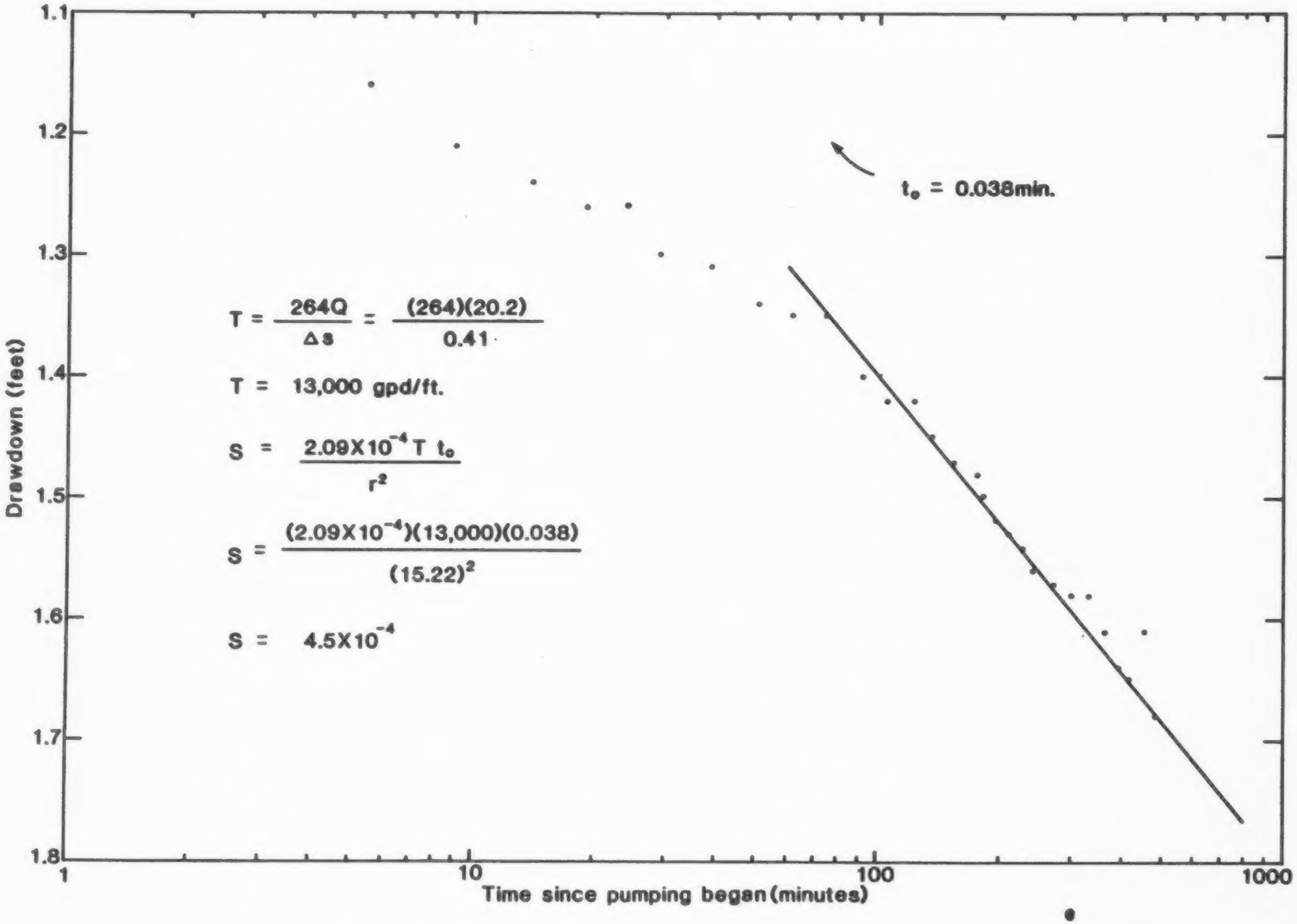


Figure C-2. Theis recovery analysis using data from well P2C2.



$$T = \frac{264Q}{\Delta s} = \frac{(264)(20.2)}{0.41}$$

$$T = 13{,}000 \text{ gpd/ft.}$$

$$S = \frac{2.09\times10^{-4}\,T\,t_o}{r^2}$$

$$S = \frac{(2.09\times10^{-4})(13{,}000)(0.038)}{(15.22)^2}$$

$$S = 4.5\times10^{-4}$$

Figure C-3. Modified Theis nonequilibrium analysis using data from well P2C3.

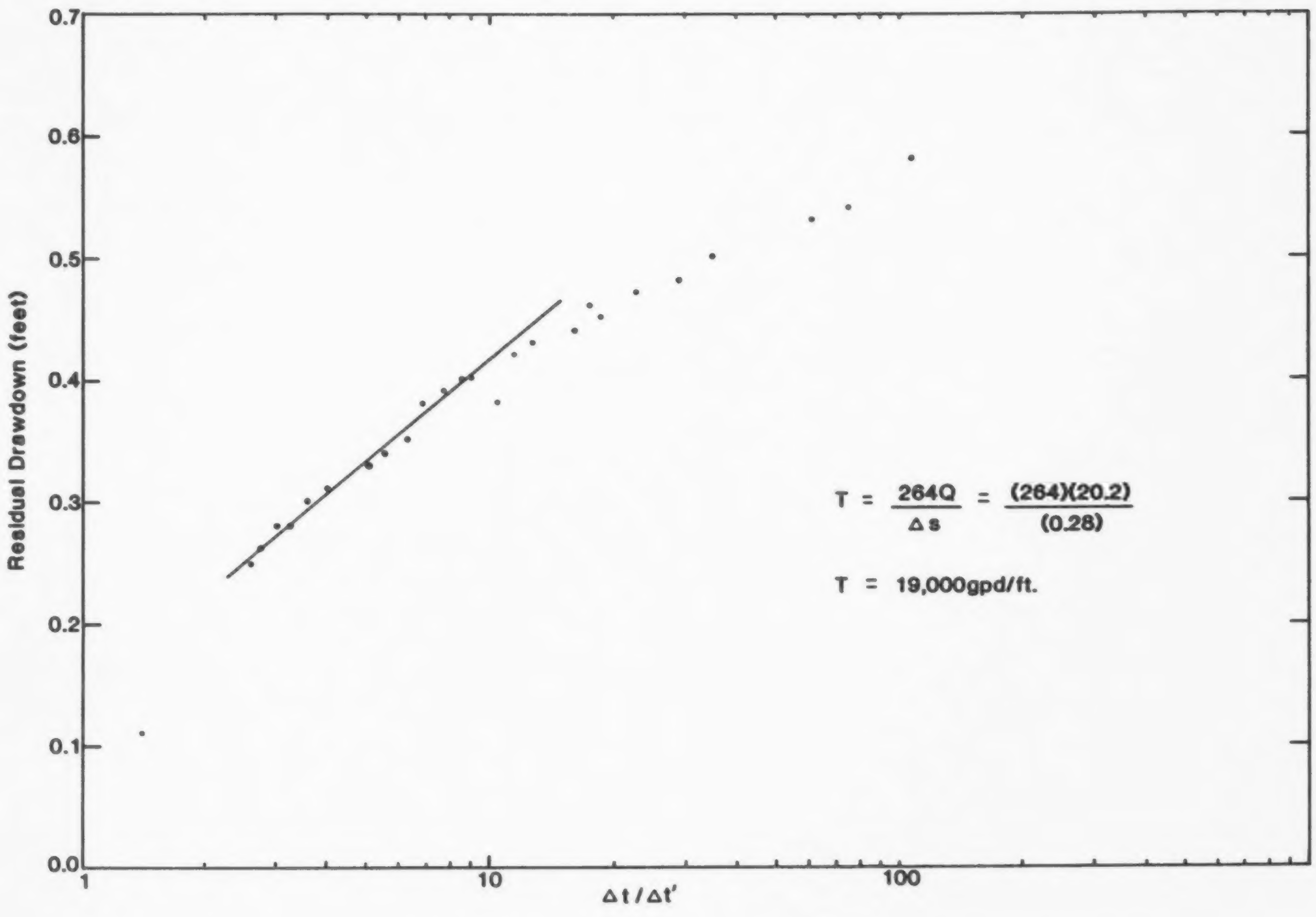


Figure C-4. Theis recovery analysis using data from well P2C3.

SECTION 3

AQUIFER PUMPING TEST
AT
SURF CITY

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AQUIFER PUMPING TEST AT SURF CITY, NC

A 4-hour aquifer pumping test was performed on August 2, 1984 in Surf City, NC. Pumping began at 0931 Eastern Daylight Time (EDT) and lasted until 1331 EDT. Well S3B2 was the pumped well. The average pumping rate from the well was 9.5 gallons per minute (gpm). The pumped water from the well was discharged to a holding tank until about 1130 EDT by which time the tank was full. The pumped water was then discharged into a slight depression located about 100 feet north of the test site. Wells S3B1, S3B3, S3B4 and S3B5 were used as observation wells.

Well construction details for the pumped well and the observation wells varied between wells. Well S3B1 is completed in unconsolidated sand deposits near the water-table surface. Wells S3B2 and S3B5 are completed in unconsolidated sand deposits about five feet above the top of limestone bedrock and about one foot above a two foot thick sandy to silty clay layer that occurs at the interface between the limestone and unconsolidated sand. Well S3B3 is completed in the limestone about 10 feet below the limestone surface. Well S3B4 is completed in the limestone about 60 feet below this surface. Construction details for the wells are summarized in Table 1. A cross-section showing the lithology at the site and the spacial relationship between wells is given in Figure 1.

Water levels were measured in the pumped well and each of the observation wells. Water-level declines were observed in the pumped well and in wells S3B1 and S3B5. The water level in wells S3B3 and S3B4 rose during the pumping period. The observed water levels and computed water level changes during pumping are presented at the end of this section.

The computed transmissivity and hydraulic conductivity for the unconsolidated deposits are 16,900 gallons per day per foot (gpd/ft) and 650 gallons per day per foot squared (gpd/ft2). The aquifer thickness used for the hydraulic conductivity computation was 27 feet. This thickness represents that from the water table approximately 6 feet below land surface to the top of the sandy to silty clay layer approximately 33 feet below land surface.

The transmissivity of the unconsolidated deposits was computed using data collected from the pumped well and from observation wells S3B1 and S3B5. The modified Theis nonequilibrium analysis (Ferris et al., 1962), together with water-level data for the pumped well, were used to compute the transmissivity of the unconsolidated deposits. Type curves developed by Stallman (Lohman, 1972) for a pumping well penetrating the bottom three-tenths of a water-table aquifer, together with water-level data collected from observation wells S3B1 and S3B5, were also used to compute transmissivity.

The storage coefficient for the unconsolidated deposits was found to be 0.04 and the vertical hydraulic conductivity for these deposits was computed to be 497 gpd/ft^2. The storage coefficient was computed using the type curves described above and water-level data collected from observation wells S3B1 and S3B5. The vertical hydraulic conductivity was computed using these type curves and water-level data collected from observation well S3B1.

TABLE 1

WELL CONSTRUCTION SUMMARY

Well number	Well depth (feet)	Well diameter (inches)	Top of open interval below land surface (feet)	Screen length (feet)
S3B1	14.2	6	8.6	5.6
S3B2	29.8	2	24.8	5.0
S3B3	48.6	2	43.6	5.0
S3B4	124	2	119	5.0
S3B5	28.4	4	24.2	4.2

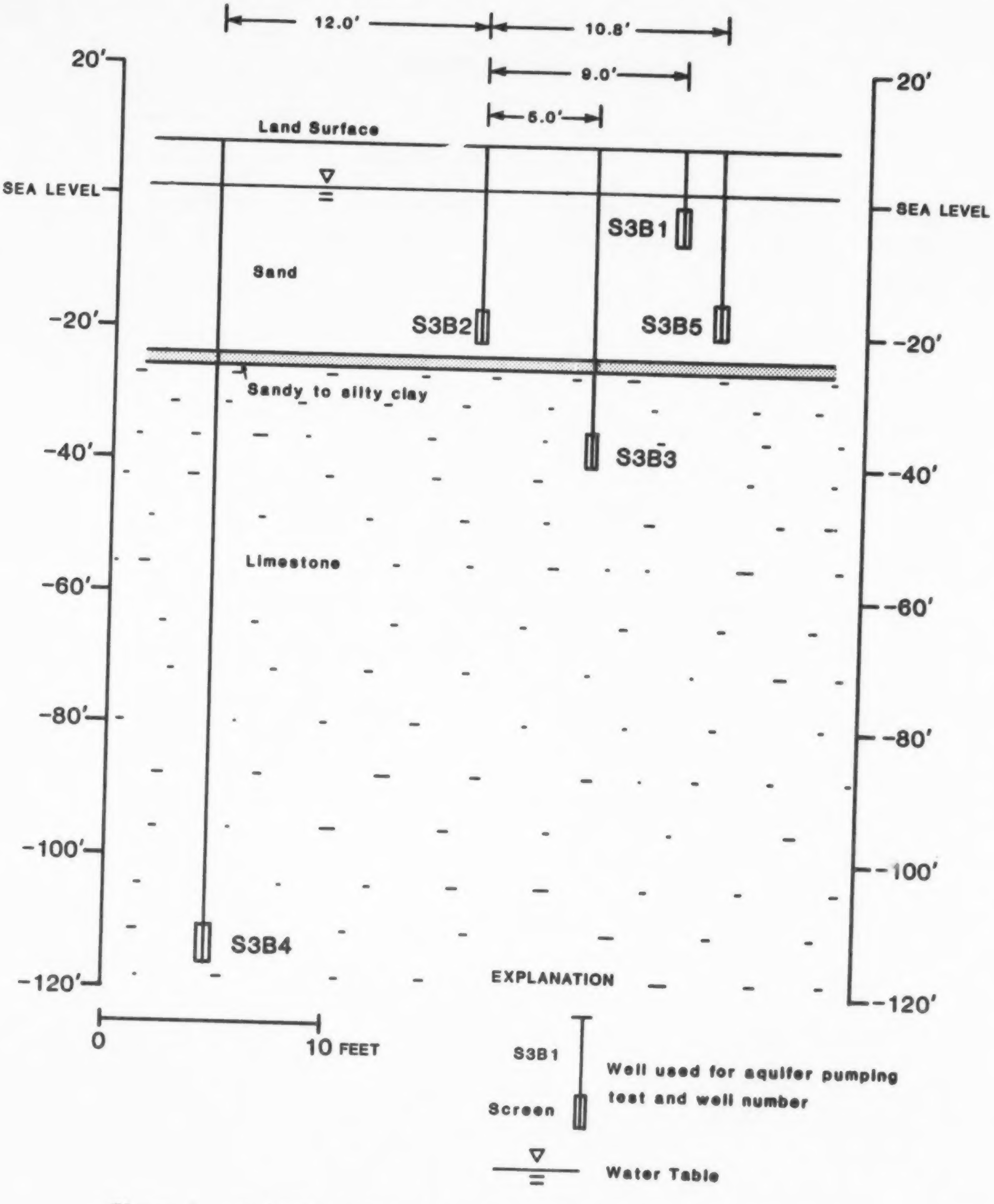

12.0'
10.8'
9.0'
5.0'
20'
Land Surface
SEA LEVEL
S3B1
Sand
-20'
S3B2
S3B5
Sandy to silty clay
-40'
S3B3
Limestone
-60'
-80'
-100'
S3B4
-120'
0
10 FEET
EXPLANATION
S3B1
Well used for aquifer pumping test and well number
Screen
Water Table

Figure 1. Geologic cross-section in vicinity of aquifer pump test site at Surf City, N.C.

The aquifer pumping test analysis is presented at the end of this section.

The rise in water levels observed in wells S3B3 and S3B4 during the aquifer pumping test suggests that the unconsolidated sand and limestone bedrock are hydraulically separated. These wells are completed in the limestone bedrock. The data collected at wells S3B3 and S3B4, although qualitatively informative, could not be used for any type of quantitative analyses.

REFERENCES

Ferris, J.B. et al., 1962. Theory of aquifer tests: United States Geological Survey Water-Supply Paper 1536-E.

Lohman, S.W. 1972. Ground-water hydraulics: United States Geological Survey Professional Paper 708.

WATER LEVELS FOR AQUIFER PUMPING TEST

Water levels were recorded for the pumped well (Well S3B2) and for wells S3B1, S3B3, S3B4 and S3B5. These data are tabulated for each well in the tables which follow. In these tables, the column headings have the following meanings:

Date:	Date of reading.
Time:	Time of reading, Eastern Daylight Time (EDT).
Depth to water:	The depth to water below the measuring point, in feet.
Flow meter reading: (Pumped well only)	The total gallons of water recorded by the flow meter. The meter reading was 994424.7 gallons prior to beginning the test.
Remarks:	Any pertinent remarks.

TABLE A1

WATER LEVEL AND PUMPING DATA FOR WELL S3B2

Date (1984)	Time (EDT)	Depth to water (feet)	Flow meter reading (gallons)	Remarks
August 2	0847	6.03		
	0930	6.03	994424.7	
	0931	-		Pump on
	0931:28	15.77		
	0931:45	15.96		
	0932	15.98		
	0932:20	15.98		
	0932:40	15.98		
	0933	16.04		Measure 9.5 gpm using flow meter
	0933:20	16.03		
	0933:40	16.04		
	0934	16.04		
	0936	16.08		
	0937:30	16.05		
	0938			Measure 9.7 gpm using flow meter
	0940	16.07		
	0943	16.09		
	0944	-	994550.0	
	0946:30	16.08		
	0950	16.09		Measure 9.7 gpm using flow meter
	0955	16.05		
	0957	-		Measure 9.6 gpm using flow meter
	0958	-	994690.0	
	1000	16.07		
	1012	16.09		Measure 9.5 gpm using flow meter
	1021	16.09		
	1031	16.08		Measure 9.5 gpm using flow meter
	1033	-	995020.0	
	1045	16.07		
	1101	16.08		
	1102	-		Measure 9.5 gpm using flow meter
	1105	-	995320.0	
	1131	16.07		
	1136	-		Measure 9.5 gpm using flow meter
	1137	-	995630.0	
	1200	-		Measure 9.6 gpm using flow meter
	1201	16.15	995860.0	
	1215	-		Measure 9.5 gpm using flow meter
	1231	16.02		
	1301	16.02		
	1305	-		Measure 9.5 gpm using flow meter
	1306	-	996480.0	
	1320	-		Measure 9.5 gpm using flow meter
	1321	16.03		
	1330	16.05		
	1331	-	996712.0	Pump off
	1331:04	12.00		
	1331:30	6.03		
	1331:45	5.95		
	1332:15	5.94		
	1334:30	5.92		
	1336:30	5.90		
	1339	5.86		
	1342	5.86		
	1345	5.85		
	1351	5.86		
	1401	5.84		
	1416	5.84		
	1431	5.85		
	1723	5.95		

Total gallons pumped is 2,287.3 gallons
Average pumping rate is 9.5 gpm

TABLE A2

WATER LEVEL DATA FOR OBSERVATION WELL S3B1

Date (1984)	Time (EDT)	Depth to water (feet)	Remarks
August 2	0743	7.85	
	0929	7.88	
	0931	-	Pump on
	0937	7.93	
	0942	7.96	
	0948	8.02	
	0957	8.01	
	1001	8.03	
	1011	8.03	
	1020	8.02	
	1030	8.02	
	1044	8.01	
	1100	8.00	
	1130	7.96	
	1200	7.95	
	1230	7.90	
	1300	7.91	
	1320	7.89	
	1331	-	Pump off
	1334	7.89	
	1338:30	7.84	
	1345	7.79	
	1350	7.77	
	1355	7.76	
	1400	7.75	
	1415	7.73	
	1430	7.74	
	1731	7.81	

TABLE A3

WATER LEVEL DATA FOR OBSERVATION WELL S3B3

Date (1984)	Time (EDT)	Depth to water (feet)	Remarks
August 2	0836	6.60	
	0927	6.60	
	0931	-	Pump on
	0938:30	6.57	
	0951	6.54	
	1002	6.55	
	1013	6.48	
	1022	6.53	
	1032	6.47	
	1046	6.44	
	1102	6.42	
	1132	6.38	
	1204	6.23	
	1232	6.24	
	1302	6.23	
	1322	6.20	
	1331		Pump off
	1335	6.18	
	1340	6.19	
	1346	6.18	
	1402	6.19	
	1417	6.17	
	1432	6.18	
	1727	6.41	

TABLE A4

WATER LEVEL DATA FOR OBSERVATION WELL S3B4

Date (1984)	Time (EDT)	Depth to water (feet)	Remarks
August 2	0736	7.34	
	0836	7.19	
	0928	7.06	
	0931	-	Pump on
	0939	6.99	
	0945	6.99	
	0952	6.97	
	1003	6.91	
	1014	6.87	
	1023	6.85	
	1033	6.79	
	1047	6.74	
	1103	6.67	
	1133	6.58	
	1205	6.50	
	1233	6.46	
	1303	6.44	
	1323	6.43	
	1331	-	Pump off
	1335:30	6.46	
	1341	6.45	
	1347	6.45	
	1403	6.48	
	1418	6.51	
	1433	6.55	
	1729	7.13	

TABLE A5

WATER LEVEL DATA FOR OBSERVATION WELL S3B5

Date (1984)	Time (EDT)	Depth to water (feet)	Remarks
August 2	0835	6.54	
	0929	6.54	
	0931	-	Pump on
	0934:20	6.64	
	0935:10	6.66	
	0941	6.73	
	0944	6.74	
	0949	6.75	
	0953	6.75	
	1004	6.75	
	1015	6.75	
	1024	6.73	
	1034	6.74	
	1048	6.71	
	1104	6.70	
	1134	6.67	
	1206	6.63	
	1234	6.68	
	1304	6.58	
	1324	6.59	
	1331	-	Pump off
	1333	6.52	
	1337:30	6.42	
	1343	6.38	
	1348	6.36	
	1356	6.36	
	1404	6.35	
	1419	6.35	
	1434	6.35	
	1730	6.46	

DRAWDOWN COMPUTATIONS FOR AQUIFER PUMPING TEST

Drawdowns in the pumped well and in the observation wells during the aquifer pumping test were computed based on the water-level observations. The drawdown computations for these wells are tabulated in the tables which follow. In these tables the column headings have the following meanings:

Date:	Date of reading.
Time:	Time of reading, Eastern Daylight Time (EDT).
Δt:	Time from start of pumping, in minutes.
$\Delta t'$:	Time since pumping stopped, in minutes.
Depth to water:	Depth to water below the measuring point, in feet.
Trend Corr.:	A correction to account for the natural trend in water levels. The correction is based on the observed water-level fluctuations in well S3B1 during the period August 6-20, 1984.
s:	Drawdown in the well, in feet. Drawdown is computed by adding the trend correction to the depth to water measurement and substracting the depth to water measured at approximately 0930 EDT on August 2, 1984 from this total.
$s^2/2M$:	A correction to account for dewatering of the aquifer system, in feet. The saturated thickness of the aquifer system in the vicinity of the test prior to pumping is represented by M. The value for M used in these computations was 27 feet. This correction is significant only for water levels at the pumped well.
s':	The drawdown in the well corrected for the effects of dewatering, in feet. This drawdown is termed residual drawdown whenever $\Delta t'$ is greater than zero.
Remarks:	Any pertinent remarks.

TABLE B1

DRAWDOWN COMPUTATIONS FOR WELL S3B2

Date (1984)	Time (EDT)	Δt (min)	Δt' (min)	$\frac{\Delta t}{\Delta t}$	Depth to water (feet)	Trend corr. (feet)	s (feet)	$\frac{s^2}{2H}$ (feet)	s' (feet)	Remarks
August 2	0930				6.03					Assume static water level
	0931									Pump on
	0931:28	0.47			15.77	0	9.74	1.75	7.99	
	0931:45	0.75			15.96	0	9.93	1.83	8.10	
	0932	1.00			15.98	0	9.95	1.83	8.12	
	0932:20	1.33			15.98	0	9.95	1.83	8.12	
	1932:40	1.67			15.98	0	9.95	1.83	8.12	
	0933	2.00			16.04	0	10.01	1.86	8.15	
	0933:20	2.33			16.03	0	10.00	1.86	8.14	
	0933:40	2.67			16.04	0	10.01	1.86	8.15	
	0934	3.00			16.04	0	10.01	1.86	8.15	
	0936	5.00			16.08	0	10.05	1.87	8.18	
	0937:30	6.50			16.05	0	10.02	1.86	8.16	
	0940	9.00			16.07	0	10.04	1.87	8.17	
	0943	12.0			16.09	.01	10.07	1.88	8.19	
	0946:30	15.5			16.08	.01	10.06	1.88	8.18	
	0950	19.0			16.09	.01	10.07	1.88	8.19	
	0955	24.0			16.05	.01	10.03	1.86	8.17	
	1000	29.0			16.07	.01	10.05	1.87	8.18	
	1012	41.0			16.09	.02	10.08	1.88	8.20	
	1021	50.0			16.09	.02	10.08	1.88	8.20	
	1031	60.0			16.08	.03	10.08	1.88	8.20	
	1045	74.0			16.07	.03	10.07	1.88	8.19	
	1101	90.0			16.08	.04	10.09	1.89	8.20	
	1131	120			16.07	.05	10.09	1.89	8.20	
	1201	150			16.15	.07	10.19	1.92	8.27	
	1231	180			16.02	.08	10.07	1.88	8.19	
	1301	210			16.02	.09	10.08	1.88	8.20	
	1321	230			16.03	.10	10.10	1.89	8.21	
	1330	239			16.05	.11	10.13	1.90	8.23	
	1331	240								Pump off
	1331:04	240	0.067	3580	12.00	.11	6.08	0.68	5.40	
	1331:30	240	0.50	480	6.03	.11	0.11	0	0.11	
	1331:45	241	0.75	321	5.95	.11	0.03	0	0.03	
	1332:15	242	1.25	194	5.94	.11	0.02	0	0.02	
	1334:30	244	3.50	69.7	5.92	.11	0.00	0	0.00	
	1336:30	245	5.50	44.5	5.90	.11	-0.02	0	-0.02	
	1339	248	8.00	31.0	5.86	.11	-0.06	0	-0.06	
	1342	251	11.0	22.8	5.86	.11	-0.06	0	-0.06	
	1345	254	14.0	18.1	5.85	.11	-0.07	0	-0.07	
	1351	260	20.0	13.0	5.86	.11	-0.06	0	-0.06	
	1401	270	30.0	9.00	5.84	.12	-0.07	0	-0.07	
	1416	285	45.0	6.33	5.84	.13	-0.06	0	-0.06	
	1431	300	60.0	5.00	5.85	.13	-0.05	0	-0.05	
	1723	472	232	2.03	5.95	.21	0.13	0	0.13	

TABLE B2

DRAWDOWN COMPUTATIONS FOR WELL S3B1

Date (1984)	Time (EDT)	Δt (min)	Δt' (min)	$\frac{\Delta t}{\Delta t}$	Depth to water (feet)	Trend corr. (feet)	s (feet)	Remarks
August 2	0929				7.88			Assume static water level
	0931							Pump on
	0937	6.00			7.93	0	0.05	
	0942	11.0			7.96	0.01	0.09	
	0948	17.0			8.02	0.01	0.15	
	0957	26.0			8.01	0.01	0.14	
	1001	30.0			8.03	0.01	0.16	
	1011	40.0			8.03	0.02	0.17	
	1020	49.0			8.02	0.02	0.16	
	1030	59.0			8.02	0.03	0.17	
	1044	73.0			8.01	0.03	0.16	
	1100	89.0			8.00	0.04	0.16	
	1130	119			7.96	0.05	0.12	
	1200	149			7.95	0.07	0.13	
	1230	179			7.90	0.08	0.10	
	1300	209			7.91	0.09	0.12	
	1320	229			7.89	0.10	0.11	
	1331	240						Pump off
	1334	243	3.00	81.0	7.89	0.11	0.12	
	1338:30	247	7.50	32.9	7.84	0.11	0.07	
	1345	254	14.0	18.1	7.79	0.11	0.02	
	1350	259	19.0	13.6	7.77	0.11	0.00	
	1355	264	24.0	11.0	7.76	0.12	0.00	
	1400	269	29.0	9.27	7.75	0.12	-0.01	
	1415	284	44.0	6.45	7.73	0.12	-0.03	
	1430	299	59.0	5.07	7.74	0.13	-0.01	
	1731	480	240	2.00	7.81	0.21	0.14	

TABLE B3

DRAWDOWN COMPUTATIONS FOR WELL S3B3

Date (1984)	Time (EDT)	Δt (min)	$\Delta t'$ (min)	$\frac{\Delta t}{\Delta t}$	Depth to water (feet)	Trend corr. (feet)	s (feet)	Remarks
August 2	0927				6.60			Assume static water level
	0931							Pump on
	0938:30	7.50			6.57	0	-0.03	
	0951	20.0			6.54	0.01	-0.05	
	1002	31.0			6.55	0.01	-0.04	
	1013	42.0			6.48	0.02	-0.10	
	1022	51.0			6.53	0.02	-0.05	
	1032	61.0			6.47	0.03	-0.10	
	1046	75.0			6.44	0.03	-0.13	
	1102	91.0			6.42	0.04	-0.14	
	1132	121			6.38	0.05	-0.17	
	1204	153			6.23	0.07	-0.30	
	1232	181			6.24	0.08	-0.28	
	1302	211			6.23	0.09	-0.28	
	1322	231			6.20	0.10	-0.30	
	1331	240						Pump off
	1335	244	4.00	61.0	6.18	0.11	-0.31	
	1340	249	9.00	27.7	6.19	0.11	-0.30	
	1346	255	15.0	17.0	6.18	0.11	-0.31	
	1402	271	31.0	8.74	6.19	0.12	-0.29	
	1417	286	46.0	6.22	6.17	0.13	-0.30	
	1432	301	61.0	4.93	6.18	0.13	-0.29	
	1727	476	236	2.02	6.41	0.21	0.02	

TABLE B4

DRAWDOWN COMPUTATIONS FOR WELL S3B4

Date (1984)	Time (EDT)	Δt (min)	Δt' (min)	$\frac{\Delta t}{\Delta t}$	Depth to water (feet)	Trend corr. (feet)	s (feet)	Remarks
August 2	0928				7.06			Assume static water level
	0931							Pump on
	0939	8.00			6.99	0	-0.07	
	0945	14.0			6.99	0.01	-0.06	
	0952	21.0			6.97	0.01	-0.08	
	1003	32.0			6.91	0.01	-0.14	
	1014	43.0			6.87	0.02	-0.17	
	1023	52.0			6.85	0.02	-0.19	
	1033	62.0			6.79	0.03	-0.24	
	1047	76.0			6.74	0.03	-0.29	
	1103	92.0			6.67	0.04	-0.35	
	1133	122			6.58	0.05	-0.43	
	1205	154			6.50	0.07	-0.49	
	1233	182			6.46	0.08	-0.52	
	1303	212			6.44	0.09	-0.53	
	1323	232			6.43	0.10	-0.53	
	1331	240						Pump off
	1335:30	244	4.5	54.2	6.46	0.11	-0.40	
	1341	250	10.0	25.0	6.45	0.11	-0.50	
	1347	256	16.0	16.0	6.45	0.11	-0.50	
	1403	272	32.0	8.50	6.48	0.12	-0.46	
	1418	287	47.0	6.11	6.51	0.13	-0.42	
	1433	302	62.0	4.87	6.55	0.13	-0.38	
	1729	478	238	2.01	7.13	0.21	0.28	

TABLE B5

DRAWDOWN COMPUTATIONS FOR WELL S3B5

Date (1984)	Time (EDT)	Δt (min)	$\Delta t'$ (min)	$\frac{\Delta t}{\Delta t}$	Depth to water (feet)	Trend corr. (feet)	s (feet)	Remarks
August 2	0929				6.54			Assume static water level
	0931							Pump on
	0934:20	3.33			6.64	0	0.10	
	0935:10	4.17			6.66	0	0.12	
	0941	10.0			6.73	0	0.19	
	0944	13.0			6.74	0.01	0.21	
	0949	18.0			6.75	0.01	0.22	
	0953	22.0			6.75	0.01	0.22	
	1004	33.0			6.75	0.01	0.22	
	1015	44.0			6.75	0.02	0.23	
	1024	53.0			6.73	0.02	0.21	
	1034	63.0			6.74	0.03	0.23	
	1048	77.0			6.71	0.03	0.20	
	1104	93.0			6.70	0.04	0.20	
	1134	123			6.67	0.05	0.18	
	1206	155			6.63	0.07	0.16	
	1234	183			6.68	0.08	0.22	
	1304	213			6.58	0.09	0.13	
	1324	233			6.59	0.10	0.15	
	1331	240						Pump off
	1333	242	2.00	121	6.52	0.11	0.09	
	1337:30	246	6.50	37.8	6.42	0.11	-0.01	
	1343	252	12.0	21.0	6.38	0.11	-0.05	
	1348	257	17.0	15.1	6.36	0.11	-0.07	
	1356	265	25.0	10.6	6.36	0.12	-0.06	
	1404	273	33.0	8.27	6.35	0.12	-0.07	
	1419	288	48.0	6.00	6.35	0.13	-0.06	
	1434	303	63.0	4.81	6.35	0.13	-0.06	
	1730	479	239	2.00	6.46	0.21	0.13	

AQUIFER PUMPING TEST ANALYSIS

Water-level data for the pumped well and for observation wells S3B1 and S3B5 were used to compute the hydraulic properties of the unconsolidated deposits. The modified Theis nonequilibrium analysis and water-level data for the the pumped well were used to compute transmissivity. Type curves developed by Stallman (Lohman, 1972) and water-level data for observation wells S3B1 and S3B5 were used to compute transmissivity and storage coefficient. Additionally, vertical hydraulic conductivity for the unconsolidated deposits was computed using water level data from observation well S3B1.

Drawdowns observed during early times in the aquifer pumping test were used for the analysis. Changes in water levels caused by the ocean tide began to strongly influence changes in drawdown due to pumping after 10 to 20 minutes of pumping.

The form of the modified Theis nonequilibrium analysis formula used for the computations is

$$T = \frac{264Q}{\Delta s}$$

The variables in the above equation have the following meaning:

T = transmissivity, in gallons per day per foot;

Q = average pumping rate, in gallons per minute; and

Δs = change in drawdown over one log-cycle for a semi-log plot of time and drawdown.

Type curves developed by Stallman (Lohman, 1972) for a pumping well penetrating the bottom three-tenths of a water-table aquifer were used for matching the drawdowns observed in monitoring wells S3B1 and S3B5. The forms of the equations used in the computations are

$$T = \frac{1440QW(U_B\ \Psi)}{s}$$

where: $$\frac{1}{U_B} = \frac{Tt}{10{,}770r^2\ S}$$

and $$\Psi = r\left(\frac{Kv}{bT}\right)^{1/2}$$

The variables in the above equations that have not previously been defined have the following meanings:

s = drawdown in the observation well at the match point, in feet;

$W(U_B, \Psi)$ = for observation well S3B5, the well function for a pumping well penetrating the bottom three-tenths of a water-table aquifer and an observation well completed near the aquifer base, no dimensions;

$W(U_B, \Psi)$ = for observation well S3B1, the well function for a pumping well penetrating the bottom three-tenths of a water-table aquifer and an observation well completed near the water table, no dimensions;

r = distance from pumping well to observation well, in feet;

S = storage coefficient, no dimensions;

t = time at the match point, in minutes;

Kv = vertical hydraulic conductivity of the aquifer, in gallons per day per foot squared; and

b = initial aquifer saturated thickness, in feet.

The parameters $W(U_B,\Psi)$, U_B,Ψ, S and T were determined by matching log-log plots of time and drawdown data to the type curves for $W(U_B\Psi)$ and $1/U_B$ developed by Stallman.

The data plots and data analyses are presented in Figures C1, C2 and C3.

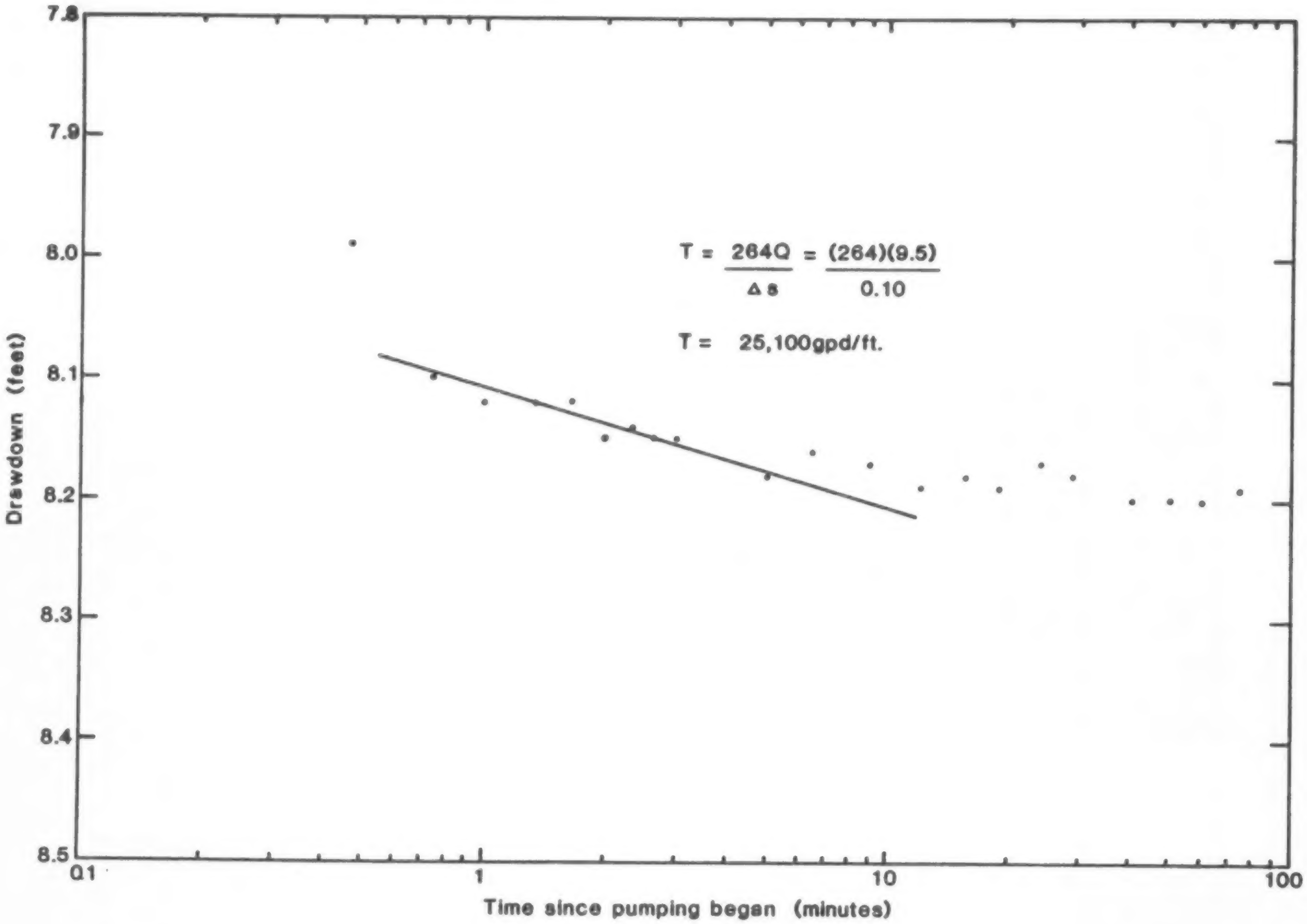
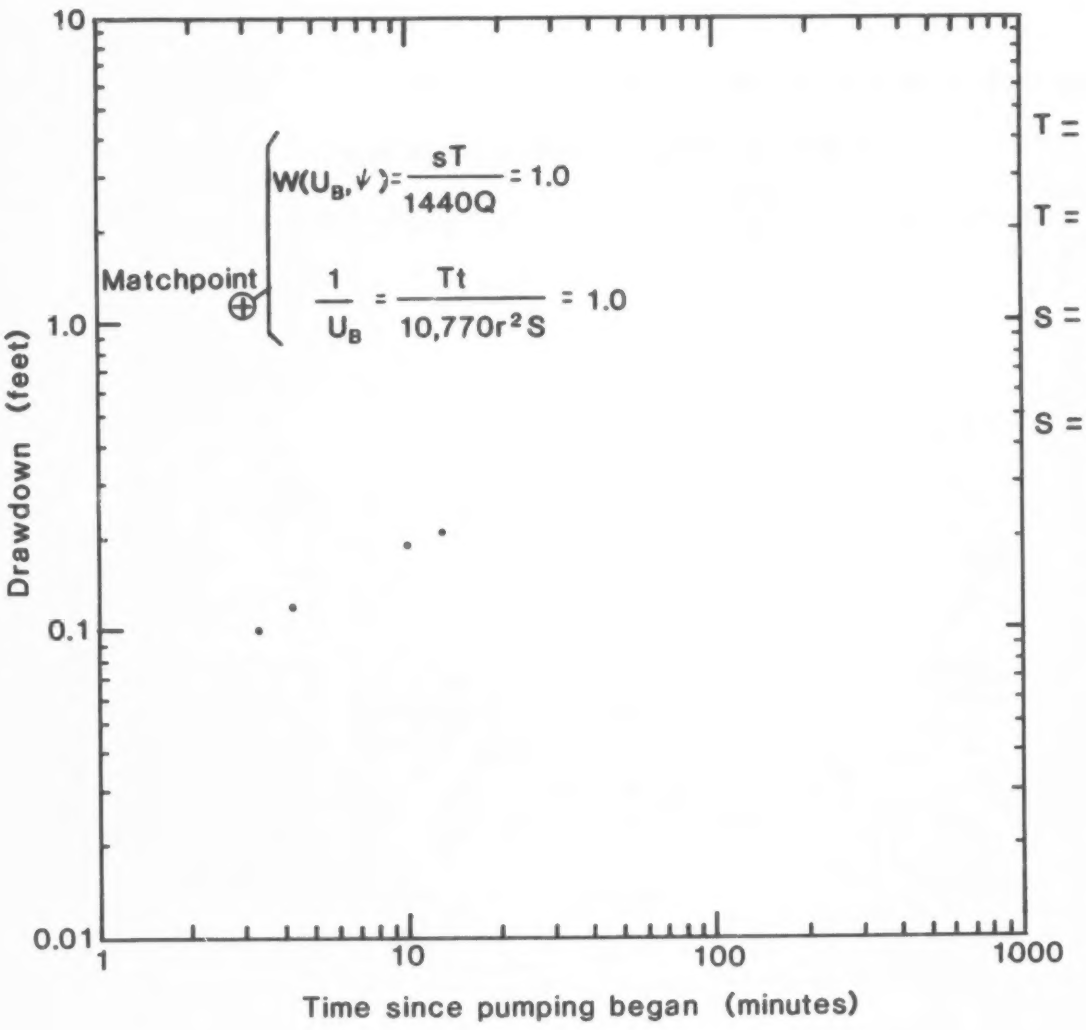


Figure C-1. Modified Theis nonequilibrium analysis using data from well S3B2.



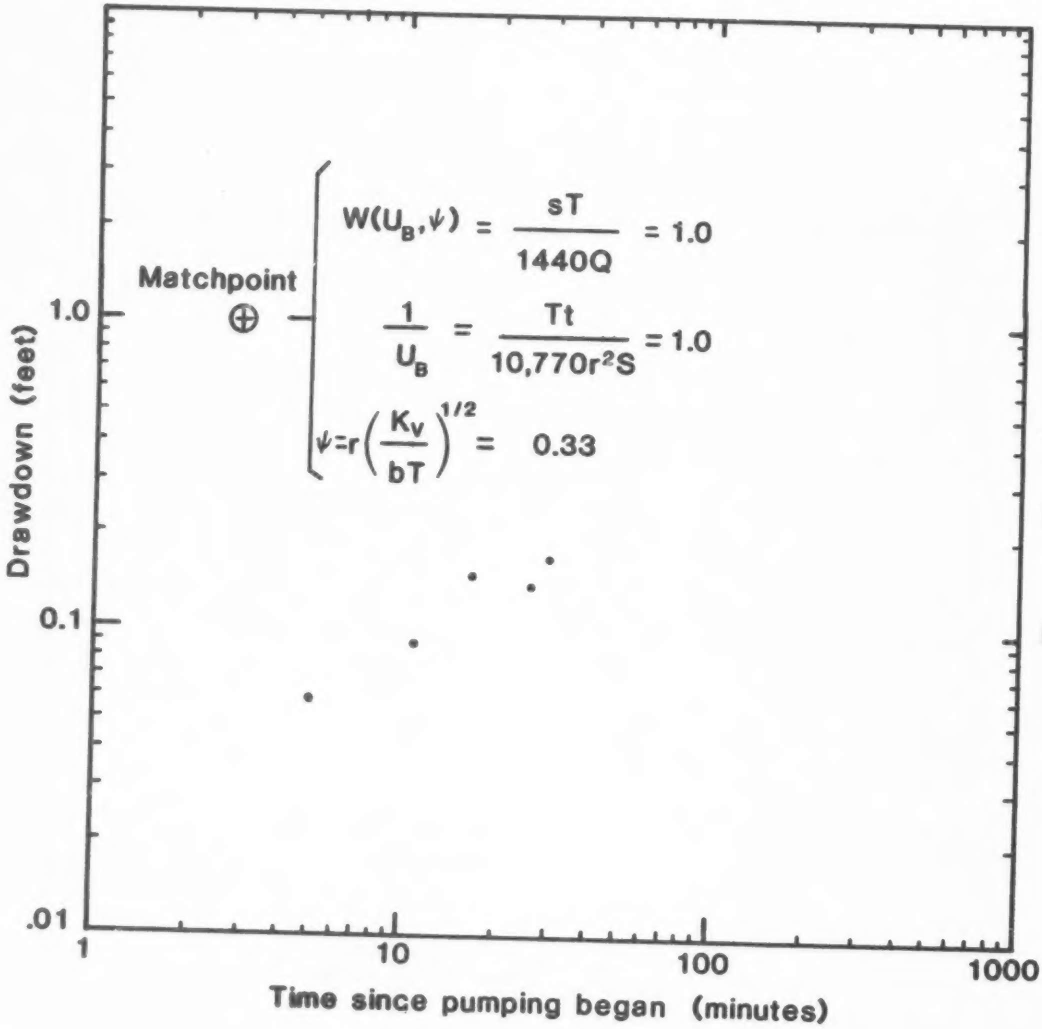
$$T = \frac{1440Q}{s} = \frac{(1440)(9.5)}{1.15}$$

$$T = 11{,}900 \text{gpd/ft.}$$

$$S = \frac{Tt}{10{,}770r^2} = \frac{(11{,}900)(3.0)}{(10{,}770)(10.8)^2}$$

$$S = 0.028$$

Figure C-2. Nonequilibrium analysis using data from well S3B5.



$$T = \frac{1440Q}{s} = \frac{(1440)(9.5)}{1.00}$$

$$T = 13{,}700 \text{ gpd/ft.}$$

$$S = \frac{Tt}{10{,}770r^2} = \frac{(13{,}700)(30)}{(10{,}770)(9.0)^2}$$

$$S = 0.047$$

$$K_v = \frac{(0.33)^2 bT}{r^2} = \frac{(0.33)^2(27)(13{,}700)}{(9.0)^2}$$

$$K_v = 497 \text{ gpd/ft.}^2$$

Figure C-3. Nonequilibrium analysis using data from well S3B1.

APPENDIX D

ELEVATION DATA

The mean sea level elevation of the water-level measuring point on each monitoring well and ocean tidal guage well and the mean sea elevation of the zero elevation for each sound tidal guage were determined. These data are tabulated in the tables that follow. In these tables, the column headings have the following meaning:

Well site:	The well site identifier.
Well ID:	The well identifier.
Measuring point elevation:	The elevation of the measuring point on the well, in feet mean sea level.
Land surface elevation:	The elevation of land surface at the well, in feet mean sea level.
Bench mark elevation:	The elevation of the bench mark established in the well site vicinity, in feet mean sea level.
Bench mark description:	A general description of the bench mark established at the well site and the bench mark location.

TABLE 1

SUMMARY OF ELEVATION DATA FOR KILL DEVIL HILLS

Well site	Well ID	Measuring point elevation (MSL)	Land surface elevation (MSL)	Bench mark elevation (MSL)	Bench mark description
K1A	K1A1	11.897	11.1	13.443	Top of concrete right-of-way monument on southwest corner of Chowan Avenue and Business Route 158.
	K1A2	11.767	10.9		
	K1A3	11.890	10.0		
K1B	K1B1	10.380	9.7	9.367	Top of concrete right-of-way monument on southeast corner of Chowan Avenue and Bypass Route 158.
K1C	K1C1	9.607	10.0	9.961	Nail in side of wooden post at well site.
	K1C4	9.727	10.0		
	K1C5	9.614	9.9		
K1D	K1D1	10.032	10.2	12.028	Nail in top of wooden post at well site.
K1E	K1E1	5.415	4.6	6.182	Spike in maple tree about 20 feet west of well site.
	K1E2	5.213	4.4		
	K1E3	5.809	4.9		
K2A	K2A1	12.470	11.3	13.609	Nail in top of guard post at well site.
	K2A2	12.044	10.9		
	K2A3	12.186	11.1		
K2B	K2B1	9.258	8.3	8.779	Top of concrete right-of-way monument on southeast corner of 5th street and Bypass Route 158.
	K2B2	9.200	9.0		
	K2B3	8.739	7.8		
K2C	K2C1	9.380	9.5	9.668	Nail in stop sign post on Wilbur Court at southeast corner of intersection with 5th street.
	K2C2	9.380	9.7		
	K2C3	9.310	9.6		
	K2C4	8.977	9.3		
K2D	K2D1	11.798	12.1	13.621	Nail in top of wooden post at well site.
	K2D2	12.009	12.3		
	K2D3	12.037	12.3		
K2E	K2E1	5.318	4.3	6.365	Nail in top of wooden post at well site.
	K2E2	5.177	4.3		
	K2E3	5.460	4.4		
K3A	K3A1	13.584	12.8	13.215	Nail in north side of wooden ramp at base of first railing post.
	K3A2	13.525	13.0		
	K3A2B	12.941	11.9		
	K3A3B	13.165	12.2		
K3B	K3B1	10.288	9.6	9.098	Nail in pole VPCo D153 on southeast corner of Ocean Bay Boulevard and Mustian Street.
K3C	K3C1	13.965	12.9	4.585	Top nail in pole 14 along fence.
K3D	K3D1	15.737	13.9	16.332	Nail in top of third guard post south of private road entrance.
	K3D2	17.328	13.9		
	K3D3	14.675	13.5		

TABLE 1
(continued)
SUMMARY OF ELEVATION DATA FOR KILL DEVIL HILLS

Well site	Well ID	Measuring point elevation (MSL)	Land surface elevation (MSL)	Bench mark elevation (MSL)	Bench mark description
K3E	K3E1	13.040	12.2	14.645	Nail in wooden post about 15 feet south of fence line and about 60 feet north of well site.
K3F	K3F1	12.946	11.4	12.407	Nail in guard post about 20 feet east of well site.
K3G	K3G1	6.469	5.4	7.813	Nail in top of wooden post at well site.
	K3G2	6.524	5.3		
	K3G3	6.480	5.1		
Ocean gauge		16.75		17.341	Mark on deck immediately above stilling well pipe.
Sound gauge		-0.25[a]		6.534	Top of post on south pier.

[a] Elevation of zero reading on staff gauge.

TABLE 2

SUMMARY OF ELEVATION DATA FOR ATLANTIC BEACH

Well site	Well ID	Measuring point elevation (MSL)	Land surface elevation (MSL)	Bench mark elevation (MSL)	Bench mark description
A1A	A1A1	10.675	9.8	10.668	Nail in top of west guard post at Dunes Avenue and Boardwalk Avenue.
	A1A3	10.619	9.9		
A1B	A1B1	8.748	8.0	8.730	Nail in side of "Community Watch" sign at well site.
	A1B3	8.683	8.0		
A1C	A1C1	11.133	10.3	12.305	Top of iron pipe next to utility pole on east side of Dunes Avenue across from well site.
	A1C3	10.984	10.0		
A1D	A1D1	4.976	5.3	6.969	Nail in top of wooden post at well site.
	A1D2	4.823	5.1		
	A1D3	5.055	5.4		
A2A	A2A1	10.120	11.3	10.632	Nail in top of wooden post at well site.
	A2A3	10.081	11.3		
	A2A4	9.921	11.3		
A2B	A2B1	6.671	7.0	8.643	Nail in top of wooden post at well site.
	A2B3	6.602	6.9		
	A2B4	6.752	7.0		
A2C	A2C1	4.445	4.9	6.382	Nail in top of wooden post at well site.
	A2C3	4.610	4.9		
	A2C4	4.559	4.9		
Ocean gauge		16.89		17.935	Mark on deck immediately above stilling well pipe.
Sound gauge		-1.86[a]		6.121	Top of post at staff gauge location.

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[a] Elevation of zero reading on staff gauge.

TABLE 3

SUMMARY OF ELEVATION DATA FOR PINE KNOLL SHORES

Well site	Well ID	Measuring point elevation (MSL)	Land surface elevation (MSL)	Bench mark elevation (MSL)	Bench mark description
P1A	P1A1	15.250	14.0	16.162	Nail in top of wooden post at well site.
	P1A2	15.281	14.3		
	P1A3	15.316	14.0		
P1B	P1B1	13.173	12.3	16.901	Top of concrete right-of-way monument on southwest corner of Yaupon Road and Salter Path Road.
P1C	P1C1	7.543	7.8	9.545	Nail in top of wooden post at well site.
	P1C2	7.429	7.8		
	P1C3	7.552	7.9		
	P1C4	7.553	7.9		
P1D	P1D1	10.951	11.4	13.184	Top of iron pipe between 127 and 129 Yaupon Road.
P1E	P1E1	9.327	8.2	8.971	Nail in stop sign post at intersection of Yaupon Road and Oakleaf Drive.
	P1D2	9.385	8.2		
	P1E3	9.290	8.3		
P2A	P2A1	14.799	15.2	15.370	Nail in edge of bituminous parking lot at well site.
	P2A2	14.921	15.3		
	P2A3	15.111	15.4		
P2B	P2B1	11.550	10.7	12.091	Top of concrete right-of-way monument on northwest corner of Pine Knoll Boulevard and Salter Path Road.
P2C	P2C1	9.380	6.9	7.207	Nail in edge of road about 14 feet east of well site.
	P2C2	8.426	6.9		
	P2C3	7.911	6.9		
	P2C4	7.811	7.0		
P2D	P2D1	8.965	8.1	7.758	Nail in utility pole on southeast corner of Pine Knoll Boulevard and Ramsey Drive.
P2E	P2E1	7.158	6.4	5.812	Top of manhole frame on McGinnis Drive near well site.
	P2E2	7.069	6.0		
	P2E3	7.164	6.3		

TABLE 4

SUMMARY OF ELEVATION DATA FOR SURF CITY

Well site	Well ID	Measuring point elevation (MSL)	Land surface elevation (MSL)	Bench mark elevation (MSL)	Bench mark description
S1A	S1A1	9.334	9.7	10.337	Nail in pole near ramp leading to beach at Pender Avenue and Shore Drive.
	S1A2	9.079	9.6		
	S1A3	9.442	9.6		
S1B	S1B1	5.575	5.8	6.880	Nail in utility pole at motel on corner of Pender Avenue and New River Drive.
	S1B2	5.369	5.7		
	S1B3	5.262	5.6		
S3A	S3A1	12.260	11.7	11.692	Top of concrete monument on southeast corner of Shore Drive and Goldsboro Avenue.
	S3A2	12.035	11.7		
	S3A3	11.922	11.5		
S3B	S3B1	9.948	8.6	9.457	Nail in pole NA-6 on corner of Goldsboro Avenue and Topsail Avenue.
	S3B2	7.785	8.1		
	S3B3	7.819	8.2		
	S3B4	8.147	8.6		
	S3B5	8.323	8.7		
S3C	S3C1	4.828	3.7	5.457	Nail in pole at Surf City rescue squad building.
	S3C2	5.304	4.0		
	S3C3	5.585	4.3		
Ocean gauge		22.005			
Sound gauge		-0.50[a]			

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[a] Elevation of zero reading on staff gauge.

APPENDIX E

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WATER LEVEL DATA

Ground-water level data were collected periodically in each study area, as were water-level data for the ocean and sound at each area. These data are tabulated in the tables that follow along with water-level elevations computed from the data. In these tables, the column headings have the following meaning:

Well ID (monitoring wells only):	The well identifier.
Measurement date:	The date of the measurement.
Measurement time:	The time of the measurement.
Depth to water from measuring points (monitoring wells and ocean tidal gauges):	The distance, in feet, from the measuring point to the water surface.
Staff gauge reading (sound gauges only):	The water level, in feet, read directly from a staff gauge graduated in 0.02 foot increments.
Water level elevation:	The mean sea level elevation of the water surface computed from the data.

WATER-LEVEL DATA
FOR
KILL DEVIL HILLS

TABLE 1

ATLANTIC OCEAN TIDAL MEASUREMENTS AT KILL DEVIL HILLS

Measurement Date	Measurement Time	Depth to water from measuring point (ft)	Water level elevation (MSL)
10 Jul 84	1210		-1.2[a]
17 Aug	0437		-1.0[a]
	1058		1.9[a]
	1711		-0.7[a]
	2307		1.6[a]
	0514		-0.9[a]
	1140		1.9[a]
17 Sep	1720	15.31	1.44
18 Sep	0758	15.87	0.88
	0858	15.71	1.04
19 Oct	1712	13.99	2.76
20 Oct	0856	16.81	-0.06
21 Oct	0821	16.31	0.62
12 Nov	1237	15.01	1.74
	1626	16.81	-0.06
13 Nov	0704	15.74	1.01
	0824	14.21	2.54
10 Dec	1353		-1.3[a]
11 Dec	0807		1.8[a]
15 Jan 85	1446[a]		1.5[a]
9 Feb	1330	17.39	-0.64
	1610	18.83	-2.08
	2040	15.64	1.11
10 Feb	0018	15.51	1.24
	0433	18.16	-1.41
6 Mar	1505		-0.7[a]
9 Apr	0911		1.0[a]
6 May	1622		-0.5[a]

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[a] Estimated from tidal tables (NOAA, 1985).

TABLE 2

ALBEMARLE SOUND TIDAL MEASUREMENTS AT KILL DEVIL HILLS

Measurement Date	Measurement Time	Staff gauge reading (ft)	Water level elevation (MSL)
11 Jul 84	1440	1.34	1.09
17 Aug	0811	1.28	1.03
	1125	1.23	0.98
	1531	1.21	0.96
	2104	1.21	0.96
18 Aug	0037	1.30	1.05
	0432	1.39	1.14
17 Sep	1730	0.56	0.31
18 Sep	0750	0.70	0.45
	0908	0.62	0.37
19 Oct	1722	1.84	1.59
20 Oct	0948	1.92	1.67
21 Oct	0920	1.92	1.67
12 Nov	1249	1.55	1.30
	1618	1.48	1.23
13 Nov	0713	1.40	1.15
	0834	1.50	1.25
10 Dec	1357	0.88	0.63
11 Dec	0845	0.86	0.61
	1104	0.92	0.67
15 Jan 85	1410	1.24	0.99
	1550	1.18	0.93
9 Feb	0932	0.91	0.66
	1434	0.96	0.71
	1712	0.75	0.50
	2205	0.65	0.40
10 Feb	0139	0.91	0.66
	0620	0.60	0.35
6 Mar	1409	0.70	0.45
	1639	0.53	0.28
9 Apr	0853	1.55	1.30
	1002	1.50	1.25
10 Apr	0806	0.40	0.15
	1120	0.30	0.05
6 May	1551	1.30	1.07
	1830	1.35	1.10

TABLE 3

GROUND-WATER LEVEL MEASUREMENTS AT KILL DEVIL HILLS

Well I.D.	Measurement Date	Measurement Time	Depth to water from measuring point (ft)	Water level elevation (MSL)
K1A1	9 Jul 84	1100	8.88	3.02
	17 Aug	0655	8.88	3.02
		1049	8.91	2.99
		1458	8.90	3.00
		2017	8.86	3.04
		2359	8.92	2.98
	18 Aug	0359	8.87	3.03
	18 Sep	0852	6.69	5.21
		0926	6.69	5.21
	20 Oct	0904	4.77	7.13
		0956	4.78	7.12
	13 Nov	0739	6.38	5.52
		0812	6.38	5.52
	11 Dec	0812	8.20	3.70
		0959	8.20	3.70
	15 Jan 85	1345	8.14	3.76
		1535	8.15	3.75
	9 Feb	0830	7.83	4.07
		1345	7.84	4.06
		1618	7.85	4.05
		2050	7.88	4.02
	10 Feb	0027	7.94	3.96
		0440	7.90	4.00
	6 Mar	1336	8.37	3.53
		1617	8.35	3.55
	10 Apr	0703	8.32	3.58
		1044	8.34	3.56
	6 May	1415	7.95	3.95
		1742	8.01	3.89
K1A2	9 Jul 84	1110	8.72	3.05
	17 Aug	0650	8.72	3.05
		1051	8.76	3.01
		1500	8.74	3.03
		2019	8.73	3.04
	18 Aug	0002	8.73	3.04
		0401	8.72	3.05
	18 Sep	0851	6.55	5.22
		0925	6.54	5.23
	20 Oct	0905	4.66	7.11
		0957	4.67	7.10
	13 Nov	0739	6.23	5.54
		0813	6.24	5.53
	11 Dec	0813	8.03	3.74
		1000	8.03	3.74
	15 Jan 85	1345	8.00	3.77
		1535	8.00	3.77
	9 Feb	0831	7.67	4.10
		1346	7.70	4.07
		1619	7.73	4.04
		2052	7.73	4.04
	10 Feb	0028	7.78	3.99
		0441	7.76	4.01
	6 Mar	1336	8.22	3.55
		1616	8.21	3.56
	10 Apr	0704	8.18	3.59
		1045	8.20	3.57
	6 May	1416	7.84	3.86
		1742	7.89	3.88

TABLE 3
(continued)
GROUND-WATER LEVEL MEASUREMENTS AT KILL DEVIL HILLS

Well I.D.	Measurement Date	Measurement Time	Depth to water from measuring point (ft)	Water level elevation (MSL)
K1A3	9 Jul 84	1115	8.83	3.06
	17 Aug	0655	8.81	3.08
		1052	8.82	3.07
		1501	8.83	3.06
		2020	8.80	3.09
	18 Aug	0003	8.81	3.08
		0358	8.88	3.01
	18 Sep	0850	6.63	5.26
		0924	6.64	5.25
	20 Oct	0905	4.80	7.09
		0957	4.81	7.08
	13 Nov	0740	6.35	5.54
		0814	6.34	5.55
	11 Dec	0814	8.10	3.79
		1001	8.10	3.79
	15 Jan 85	1346	8.07	3.82
		1535	8.09	3.80
	9 Feb	0832	7.72	4.17
		1347	7.81	4.08
		1620	7.81	4.08
		2054	7.87	4.02
	10 Feb	0030	7.87	4.02
		0443	7.87	4.02
	6 Mar	1335	8.32	3.57
		1615	8.31	3.58
	10 Apr	0705	8.28	3.61
		1045	8.31	3.58
	6 May	1417	7.97	3.92
		1743	8.01	3.88
K1B1	10 Jul 84	1050	4.63	5.75
	17 Aug	0706	4.85	5.53
		1058	4.86	5.52
		1509	4.87	5.51
		2028	4.87	5.51
	18 Aug	0010	4.89	5.49
		0408	4.91	5.47
	18 Sep	0846	3.29	7.09
		0922	3.30	7.08
	20 Oct	0916	4.06	6.32
		1003	4.06	6.32
	13 Nov	0734	3.99	6.39
		0808	4.00	6.38
	11 Dec	0820	4.27	6.11
		1013	4.28	6.10
	15 Jan 85	1350	4.80	5.58
		1540	4.82	5.56
	9 Feb	0837	4.32	6.06
		1350	4.33	6.05
		1625	4.34	6.04
		2058	4.38	6.00
	10 Feb	0034	4.39	5.99
		0501	4.37	6.01
	6 Mar	1342	4.52	5.96
		1621	4.43	5.95
	10 Apr	0723	4.87	5.51
		1048	4.88	5.50
	6 May	1427	5.29	5.09
		1748	5.28	5.10

TABLE 3
(continued)
GROUND-WATER LEVEL MEASUREMENTS AT KILL DEVIL HILLS

Well I.D.	Measurement Date	Measurement Time	Depth to water from measuring point (ft)	Water level elevation (MSL)
K1C1	9 Jul 84	1500	3.38	6.23
	17 Aug	0703	3.73	5.88
		1106	3.73	5.88
		1512	3.75	5.86
		2035	3.75	5.86
	18 Aug	0018	3.75	5.86
		0413	3.76	5.85
	18 Sep	0841	2.26	7.35
		0918	2.26	7.35
	20 Oct	0921	3.18	6.43
		1007	3.18	6.43
	13 Nov	0730	3.33	6.28
		0759	3.34	6.27
	11 Dec	0824	3.45	6.16
		1019	3.45	6.16
	15 Jan 85	1355	3.98	5.63
		1543	3.98	5.63
	9 Feb	0841	3.42	6.19
		1353	3.41	6.20
		1628	3.44	6.17
		2100	3.44	6.17
	10 Feb	0036	3.45	6.16
		0506	3.43	6.18
	6 Mar	1350	3.36	6.25
		1625	3.36	6.25
	10 Apr	0731	3.81	5.80
		1050	3.81	5.80
	6 May	1433	4.29	5.32
		1750	4.29	5.32
K1C4	9 Jul 84	1500	3.70	6.03
	17 Aug	0704	4.05	5.68
		1102	4.05	5.68
		1513	4.06	5.67
		2037	4.06	5.67
	18 Aug	0014	4.08	5.65
		0414	4.09	5.64
	18 Sep	0842	2.55	7.18
		0919	2.55	7.18
	20 Oct	0921	3.49	6.24
		1007	3.49	6.24
	13 Nov	0731	3.63	6.10
		0759	3.64	6.09
	11 Dec	0825	3.77	5.96
		1020	3.77	5.96
	15 Jan 85	1355	4.30	5.43
		1543	4.29	5.44
	9 Feb	0841	3.42	6.19
		1354	3.77	5.96
		1629	3.78	5.95
		2102	3.77	5.96
	10 Feb	0038	3.80	5.93
		0507	3.80	5.93
	6 Mar	1348	3.70	6.03
		1624	3.70	6.03
	10 Apr	0732	4.15	5.58
		1051	4.16	5.57
	6 May	1434	4.60	5.13
		1751	4.61	5.12

TABLE 3
(continued)
GROUND-WATER LEVEL MEASUREMENTS AT KILL DEVIL HILLS

Well I.D.	Measurement Date	Measurement Time	Depth to water from measuring point (ft)	Water level elevation (MSL)
K1C5	9 Jul 84	1501	3.60	6.01
	17 Aug	0705	3.94	5.67
		1105	3.94	5.67
		1515	3.96	5.65
		2040	3.95	5.66
	18 Aug	0016	3.97	5.64
		0416	3.98	5.63
	18 Sep	0844	2.44	7.17
		0920	2.44	7.17
	20 Oct	0922	3.38	6.23
		1008	3.38	6.23
	13 Nov	0731	3.53	6.08
		0800	3.52	6.09
	11 Dec	0826	3.66	5.95
		1020	3.66	5.95
	15 Jan 85	1356	4.18	5.43
		1543	4.18	5.43
	9 Feb	0843	3.67	5.94
		1355	3.67	5.94
		1630	3.68	5.93
		2103	3.69	5.92
	10 Feb	0040	3.72	5.89
		0509	3.70	5.91
	6 Mar	1349	3.60	6.01
		1625	3.60	6.01
	10 Apr	0733	4.03	5.58
		1052	4.04	5.57
	6 May	1434	4.49	5.12
		1751	4.48	5.13
K1D1	10 Jul 84	1110	5.03	5.00
	17 Aug	0716	5.12	4.91
		1109	5.13	4.90
		1518	5.12	4.91
		2047	5.13	4.90
	18 Aug	0022	5.15	4.88
		0420	5.17	4.86
	18 Sep	0836	3.69	6.34
		0916	3.69	6.34
	20 Oct	0931	4.69	5.34
		1011	4.69	5.34
	13 Nov	0725	5.02	5.01
		0754	4.99	5.04
	11 Dec	0832	5.09	4.94
		1030	5.09	4.94
	15 Jan 85	1400	5.51	4.52
		1545	5.51	4.52
	9 Feb	0846	5.06	4.97
		1358	5.07	4.96
		1633	5.06	4.97
		2107	5.38	4.65
	10 Feb	0040	5.09	4.94
		0519	5.05	4.98
	6 Mar	1359	4.98	5.05
		1629	4.98	5.05
	10 Apr	0742	5.37	4.66
		1055	5.30	4.73
	6 May	1440	5.66	4.37
		1756	5.67	4.36

TABLE 3
(continued)
GROUND-WATER LEVEL MEASUREMENTS AT KILL DEVIL HILLS

Well I.D.	Measurement Date	Measurement Time	Depth to water from measuring point (ft)	Water level elevation (MSL)
K1E1	10 Jul 84	1130	3.21	2.21
	17 Aug	0721	2.93	2.49
		1114	3.08	2.34
		1523	3.21	2.21
		2054	3.11	2.31
	18 Aug	0028	3.03	2.39
		0424	3.00	2.42
	18 Sep	0832	1.99	3.43
		0912	1.96	3.46
	20 Oct	0935	2.14	3.28
		1015	2.15	3.27
	13 Nov	0720	2.01	3.41
		0746	2.00	3.42
	11 Dec	0837	2.03	3.39
		1035	2.04	3.38
	15 Jan 85	1403	2.20	3.22
		1548	2.21	3.21
	9 Feb	0849	2.05	3.37
		1401	1.91	3.51
		1636	1.91	3.51
		2111	1.99	3.43
	10 Feb	0046	2.01	3.41
		0522	2.03	3.39
	6 Mar	1403	2.11	3.31
		1634	2.12	3.30
	10 Apr	0748	2.58	2.84
		1058	2.57	2.85
	6 May	1445	2.95	2.47
		1759	2.97	2.45
K1E2	10 Jul 84	1135	2.65	2.56
	17 Aug	0723	2.74	2.47
		1116	2.81	2.40
		1524	2.86	2.35
		2055	2.84	2.37
	18 Aug	0030	2.81	2.40
		0426	2.76	2.45
	18 Sep	0833	2.49	2.72
		0913	2.52	2.69
	20 Oct	0935	2.11	3.10
		1016	2.12	3.09
	13 Nov	0720	2.56	2.65
		0746	2.53	2.68
	11 Dec	0838	2.88	2.33
		1036	2.87	2.34
	15 Jan 85	1403	2.70	2.51
		1548	2.81	2.40
	9 Feb	0850	2.83	2.38
		1402	2.85	2.36
		2113	3.00	2.21
	10 Feb	0048	3.05	2.16
		0523	3.04	2.17
	6 Mar	1404	3.11	2.10
		1635	3.16	2.05
	10 Apr	0748	3.23	1.98
		1059	3.31	1.90
	6 May	1446	2.86	2.35
		1759	2.96	2.25

TABLE 3
(continued)
GROUND-WATER LEVEL MEASUREMENTS AT KILL DEVIL HILLS

Well I.D.	Measurement Date	Measurement Time	Depth to water from measuring point (ft)	Water level elevation (MSL)
K1E3	10 Jul 84	1125	3.26	2.55
	17 Aug	0720	3.33	2.48
		1113	3.40	2.41
		1522	3.46	2.35
		2057	3.42	2.39
	18 Aug	0026	3.40	2.41
		0427	3.33	2.48
	18 Sep	0831	3.09	2.72
		0911	3.10	2.71
	20 Oct	0936	2.70	3.11
		1016	2.71	3.10
	13 Nov	0721	3.14	2.67
		0746	3.10	2.71
	11 Dec	0838	3.47	2.34
		1037	3.46	2.35
	15 Jan 85	1404	3.26	2.55
		1548	3.41	2.40
	9 Feb	0851	3.40	2.41
		1402	3.44	2.37
		1638	3.45	2.36
		2115	3.56	2.25
	10 Feb	0050	3.61	2.20
		0524	3.63	2.18
	6 Mar	1402	3.68	2.13
		1633	3.73	2.08
	10 Apr	0749	3.80	2.01
		1100	3.89	1.92
	6 May	1447	3.45	2.36
		1800	3.44	2.37
K2A1	10 Jul 84	1435	10.03	2.44
	17 Aug	0745	10.10	2.37
		1051	10.13	2.34
		1453	10.02	2.45
		2200	10.10	2.37
	18 Aug	0125	10.03	2.44
		0515	10.03	2.44
	18 Sep	0712	8.21	4.26
		0803	8.23	4.24
	21 Oct	0831	6.57	5.90
		0927	6.62	5.85
	12 Nov	1438	7.27	5.20
		1516	7.28	5.19
	11 Dec	0923	9.44	3.03
		1156	9.37	3.10
	15 Jan 85	1438	9.25	3.22
		1613	9.21	3.26
	9 Feb	0859	8.26	4.21
		1408	8.22	4.25
		1644	8.30	4.17
		2127	8.40	4.07
	10 Feb	0055	8.26	4.21
		0531	5.65	6.82
	6 Mar	1444	9.24	3.23
		1706	9.27	3.20
	9 Apr	0826	9.26	3.21
		0936	9.28	3.19
	6 May	1500	8.66	3.81
		1806	8.80	3.67

TABLE 3
(continued)
GROUND-WATER LEVEL MEASUREMENTS AT KILL DEVIL HILLS

Well I.D.	Measurement Date	Measurement Time	Depth to water from measuring point (ft)	Water level elevation (MSL)
K2A2	10 Jul 84	1438	9.64	2.40
	17 Aug	0744	9.69	2.35
		1049	9.72	2.32
		1455	9.60	2.44
		2201	9.68	2.36
	18 Aug	0124	9.62	2.42
		0517	9.63	2.41
	18 Sep	0714	7.82	4.22
		0804	7.85	4.19
	21 Oct	0832	6.15	5.89
		0927	6.22	5.82
	12 Nov	1437	6.82	5.22
		1515	6.87	5.17
	11 Dec	0924	8.99	3.05
		1157	8.82	3.22
	15 Jan 85	1438	8.80	3.24
		1614	8.75	3.29
	9 Feb	0900	7.93	4.11
		1408	7.86	4.18
		1645	7.97	4.07
		2129	8.06	3.98
	10 Feb	0057	7.90	4.14
		0533	7.93	4.11
	6 Mar	1443	8.89	3.15
		1707	8.89	3.15
	9 Apr	0827	8.92	3.12
		0937	8.93	3.11
	6 May	1501	8.39	3.65
		1807	8.51	3.53
K2A3	10 Jul 84	1516	9.77	2.42
	17 Aug	0742	9.79	2.40
		1047	9.01	3.18
		1456	9.23	2.96
		2203	9.30	2.89
	18 Aug	0123	9.10	3.09
		0725	9.85	2.34
	18 Sep	0716	8.69	3.50
		0805	8.66	3.53
	21 Oct	0832	8.09	4.10
		0928	8.40	3.79
	12 Nov	1435	8.45	3.74
		1515	8.56	3.63
	11 Dec	0924	8.31	3.88
		1158	8.80	3.39
	15 Jan 85	1439	8.58	3.61
		1614	8.70	3.49
	9 Feb	0901	8.35	3.84
		1410	9.14	3.05
		1646	9.60	2.59
		2131	8.30	3.89
	10 Feb	0059	8.38	3.81
		0535	9.33	2.86
	6 Mar	1446	9.56	2.63
		1709	8.70	3.49
	9 Apr	0828	9.32	2.87
		0938	8.97	3.22
	6 May	1502	10.18	2.01
		1807	9.62	2.57

TABLE 3
(continued)
GROUND-WATER LEVEL MEASUREMENTS AT KILL DEVIL HILLS

Well I.D.	Measurement Date	Measurement Time	Depth to water from measuring point (ft)	Water level elevation (MSL)
K2B1	10 Jul 84	1427	4.76	4.50
	17 Aug	0735	4.96	4.30
		1059	4.96	4.30
		1505	4.97	4.29
		2149	4.98	4.28
	18 Aug	0114	4.98	4.28
		0505	4.98	4.28
	18 Sep	0723	3.44	5.82
		0810	3.44	5.82
	21 Oct	0844	3.79	5.47
		1011	3.79	5.47
	12 Nov	1443	3.64	5.62
		1531	3.65	5.61
	11 Dec	0916	4.13	5.13
		1147	4.13	5.13
	15 Jan 85	1434	4.48	4.78
		1610	4.48	4.78
	9 Feb	0905	4.11	5.15
		1414	4.11	5.15
		1650	4.31	4.95
		2134	4.14	5.12
	10 Feb	0105	4.14	5.12
		0548	4.15	5.11
	6 Mar	1436	4.27	4.99
		1702	4.29	4.97
	9 Apr	0834	4.67	4.59
		0942	4.67	4.57
	6 May	1511	5.02	4.24
		1810	5.03	4.23
K2B2	10 Jul 84	1423	4.68	4.52
	17 Aug	0734	4.89	4.31
		1101	4.88	4.32
		1506	4.89	4.31
		2150	4.88	4.32
	18 Aug	0113	4.90	4.30
		0506	4.91	4.29
	18 Sep	0722	3.38	5.82
		0809	3.38	5.82
	21 Oct	0844	3.73	5.47
		1011	3.73	5.47
	12 Nov	1444	3.60	5.60
		1532	3.60	5.60
	11 Dec	0917	4.08	5.12
		1147	4.09	5.11
	15 Jan 85	1434	4.43	4.77
		1610	4.44	4.76
	9 Feb	0906	4.06	5.14
		1415	4.06	5.14
		1651	4.08	5.12
		2136	4.10	5.10
	10 Feb	0107	4.11	5.09
		0549	4.11	5.09
	6 Mar	1436	4.22	4.98
		1703	4.24	4.96
	9 Apr	0834	4.61	4.59
		0942	4.62	4.58
	6 May	1512	4.98	4.22
		1811	4.98	4.22

TABLE 3
(continued)
GROUND-WATER LEVEL MEASUREMENTS AT KILL DEVIL HILLS

Well I.D.	Measurement Date	Measurement Time	Depth to water from measuring point (ft)	Water level elevation (MSL)
K2B3	10 Jul 84	1420	4.75	3.99
	17 Aug	0733	4.81	3.93
		1102	4.66	4.08
		1508	4.71	4.03
		2152	4.75	3.99
	18 Aug	0111	4.68	4.06
		0507	4.82	3.92
	18 Sep	0721	3.35	5.39
		0808	3.37	5.37
	21 Oct	0845	3.51	5.23
		1012	3.61	5.13
	12 Nov	1445	3.57	5.17
		1533	3.59	5.15
	11 Dec	0918	3.96	4.78
		1148	4.02	4.72
	15 Jan 85	1434	4.28	4.46
		1611	4.29	4.45
	9 Feb	0907	3.89	4.85
		1415	4.03	4.71
		1652	4.13	4.61
		2138	3.92	4.82
	10 Feb	0109	3.93	4.81
		0550	4.11	4.63
	6 Mar	1437	4.27	4.47
		1703	4.12	4.62
	9 Apr	0835	4.51	4.23
		0944	4.45	4.29
	6 May	1513	4.94	3.80
		1811	4.86	3.88
K2C1	10 Jul 84	1313	3.51	5.82
	17 Aug	0734	3.76	5.57
		1110	3.80	5.53
		1519	3.80	5.53
		2132	3.77	5.56
	18 Aug	0102	3.82	5.51
		0455	3.83	5.50
	18 Sep	0729	2.14	7.19
		0812	2.15	7.18
	21 Oct	0853	3.30	6.03
		1049	3.30	6.03
	12 Nov	1450	3.07	6.26
		1542	3.06	6.27
	11 Dec	0906	3.37	5.96
		1132	3.37	5.96
	15 Jan 85	1427	3.85	5.48
		1606	3.85	5.48
	9 Feb	0910	3.22	6.11
		1418	3.23	6.10
		1654	3.25	6.08
		2139	3.27	6.06
	10 Feb	0112	3.30	6.03
		0555	3.29	6.04
	6 Mar	1431	3.20	6.13
		1653	3.21	6.12
	9 Apr	0840	3.71	5.62
		0946	3.71	5.62
	6 May	1521	4.24	5.09
		1814	4.25	5.08

TABLE 3
(continued)
GROUND-WATER LEVEL MEASUREMENTS AT KILL DEVIL HILLS

Well I.D.	Measurement Date	Measurement Time	Depth to water from measuring point (ft)	Water level elevation (MSL)
K2C2	10 Jul 84	1310	3.92	5.46
	17 Aug	0736	4.16	5.22
		1113	4.16	5.22
		1520	4.30	5.08
		2134	4.17	5.21
	18 Aug	0104	4.16	5.22
		0456	4.19	5.19
	18 Sep	0731	2.60	6.78
		0814	2.60	6.78
	21 Oct	0853	3.64	5.74
		1050	3.64	5.74
	12 Nov	1451	3.50	5.88
		1543	3.50	5.88
	11 Dec	0908	3.74	5.64
		1132	3.75	5.63
	15 Jan 85	1427	4.19	5.19
		1607	4.20	5.18
	9 Feb	0911	3.65	5.73
		1419	3.65	5.73
		1655	3.68	5.70
		2141	3.65	5.73
	10 Feb	0113	3.73	5.65
		0556	3.70	5.68
	6 Mar	1429	3.70	5.68
		1655	3.69	5.69
	9 Apr	0839	4.11	5.27
		0947	4.11	5.27
	6 May	1522	4.60	4.78
		1814	4.62	4.76
K2C3	10 Jul 84	1307	4.60	4.71
	17 Aug	0738	4.60	4.71
		1116	4.56	4.75
		1521	4.61	4.70
		2136	4.59	4.72
	18 Aug	0105	4.58	4.73
		0458	4.62	4.69
	18 Sep	0732	3.15	6.16
		0815	3.14	6.17
	21 Oct	0854	3.98	5.33
		1050	4.01	5.30
	12 Nov	1453	3.92	5.39
		1543	3.92	5.39
	11 Dec	0910	4.15	5.16
		1133	4.17	5.14
	15 Jan 85	1428	4.55	4.76
		1607	4.55	4.76
	9 Feb	0912	4.06	5.25
		1420	4.10	5.21
		1656	4.12	5.19
		2143	4.10	5.21
	10 Feb	0115	4.11	5.20
		0557	4.15	5.16
	6 Mar	1429	4.16	5.15
		1656	4.13	5.18
	9 Apr	0838	4.52	4.79
		0948	4.51	4.80
	6 May	1523	4.97	4.34
		1815	4.95	4.36

TABLE 3
(continued)
GROUND-WATER LEVEL MEASUREMENTS AT KILL DEVIL HILLS

Well I.D.	Measurement Date	Measurement Time	Depth to water from measuring point (ft)	Water level elevation (MSL)
K2C4	10 Jul 84	1303	6.04	2.94
	17 Aug	0742	5.94	3.04
		1118	5.91	3.07
		1522	5.90	3.08
		2139	5.88	3.10
	18 Aug	0106	5.91	3.07
		0500	5.94	3.04
	18 Sep	0733	5.45	3.53
		0816	5.45	3.53
	20 Oct	0854	5.40	3.58
		1051	5.44	3.54
	12 Nov	1453	5.53	3.45
		1544	5.52	3.46
	11 Dec	0911	5.87	3.11
		1134	5.86	3.12
	15 Jan 85	1428	5.82	3.16
		1607	5.85	3.13
	9 Feb	0913	5.89	3.09
		1421	5.93	3.05
		1657	5.98	3.00
		2144	5.97	3.01
	10 Feb	0117	6.00	2.98
		0559	6.00	2.98
	6 Mar	1429	6.08	2.90
		1656	6.06	2.92
	9 Apr	0837	5.95	3.03
		0949	5.93	3.05
	6 May	1524	6.26	2.72
		1816	6.24	2.74
K2D1	10 Jul 84	1328	4.66	7.14
	17 Aug	0756	5.03	6.77
		1126	5.03	6.77
		1532	5.04	6.76
		2122	5.06	6.74
	18 Aug	0054	5.05	6.75
		0448	5.07	6.73
	18 Sep	0740	3.59	8.21
		0819	3.59	8.21
	21 Oct	0904	4.85	6.95
		1315	4.85	6.95
	12 Nov	1500	5.18	6.62
		1555	5.17	6.63
	11 Dec	0857	5.10	6.70
		1120	5.11	6.69
	15 Jan 85	1420	5.73	6.07
		1601	5.72	6.08
	9 Feb	0920	5.03	6.77
		1424	5.00	6.80
		1700	4.98	6.82
		2148	4.99	6.81
	10 Feb	0120	5.00	6.80
		0603	4.98	6.82
	6 Mar	1422	4.73	7.07
		1648	4.75	7.05
	9 Apr	0858	5.12	6.68
		0951	6.14	5.66
	6 May	1533	5.69	6.11
		1819	5.70	6.10

TABLE 3
(continued)
GROUND-WATER LEVEL MEASUREMENTS AT KILL DEVIL HILLS

Well I.D.	Measurement Date	Measurement Time	Depth to water from measuring point (ft)	Water level elevation (MSL)
K2D2	10 Jul 84	1332	7.40	4.61
	17 Aug	0759	7.61	4.40
		1128	7.62	4.39
		1533	7.65	4.36
		2124	7.66	4.35
	18 Aug	0056	7.64	4.37
		0446	7.63	4.38
	18 Sep	0739	6.29	5.72
		0818	6.29	5.72
	21 Oct	0904	7.21	4.80
		1316	7.20	4.81
	12 Nov	1458	7.25	4.76
		1556	7.26	4.75
	11 Dec	0858	7.44	4.57
		1121	7.45	4.56
	15 Jan 85	1421	7.76	4.25
		1602	7.78	4.23
	9 Feb	0921	7.32	4.69
		1425	7.35	4.66
		1701	7.36	4.65
		2150	7.38	4.63
	10 Feb	0122	7.42	4.59
		0604	7.41	4.60
	6 Mar	1423	7.37	4.64
		1649	7.39	4.62
	9 Apr	0858	7.62	4.39
		0952	7.62	4.39
	6 May	1534	8.05	3.96
		1820	8.04	3.97
K2D3	10 Jul 84	1337	7.53	4.51
	17 Aug	0803	7.73	4.31
		1129	7.75	4.29
		1535	7.77	4.27
		2126	7.78	4.26
	18 Aug	0057	7.77	4.27
		0444	7.75	4.29
	18 Sep	0742	6.45	5.59
		0820	6.45	5.59
	21 Oct	0905	7.32	4.72
		1316	7.32	4.72
	12 Nov	1503	7.35	4.69
		1554	7.36	4.68
	11 Dec	0859	7.56	4.48
		1121	7.57	4.47
	15 Jan 85	1421	7.85	4.19
		1602	7.88	4.16
	9 Feb	0922	7.44	4.60
		1426	7.46	4.58
		1702	7.47	4.57
		2152	7.50	4.54
	10 Feb	0124	7.54	4.50
		0606	7.53	4.51
	6 Mar	1420	7.50	4.54
		1647	7.50	4.54
	9 Apr	0856	7.71	4.33
		0950	7.72	4.32
	6 May	1535	8.12	3.92
		1820	8.15	3.89

TABLE 3
(continued)
GROUND-WATER LEVEL MEASUREMENTS AT KILL DEVIL HILLS

Well I.D.	Measurement Date	Measurement Time	Depth to water from measuring point (ft)	Water level elevation (MSL)
K2E1	10 Jul 84	1354	3.56	1.76
	17 Aug	0804	3.65	1.67
		1129	3.68	1.64
		1537	3.74	1.58
		2111	3.72	1.60
	18 Aug	0048	3.65	1.67
		0436	3.60	1.72
	18 Sep	0747	3.00	2.32
		0824	3.00	2.32
	21 Oct	0912	3.00	2.32
		1412	3.04	2.28
	12 Nov	1507	2.90	2.42
		1606	2.92	2.40
	11 Dec	0850	3.49	1.83
		1110	3.49	1.83
	15 Jan 85	1414	3.26	2.06
		1558	3.33	1.99
	9 Feb	0925	3.30	2.02
		1429	3.31	2.01
		1705	3.34	1.98
		2155	3.42	1.90
	10 Feb	0131	3.47	1.85
		0611	3.43	1.89
	6 Mar	1412	3.64	1.68
		1642	3.68	1.64
	9 Apr	0955	3.38	1.94
		0846	3.36	1.96
	6 May	1543	3.73	1.59
		1824	3.73	1.59
K2E2	10 Jul 84	1356	3.22	1.96
	17 Aug	0803	3.38	1.80
		1130	3.39	1.79
		1536	3.48	1.70
		2113	3.47	1.71
	18 Aug	0046	3.36	1.82
		0437	3.28	1.90
	18 Sep	0746	3.10	2.08
		0823	3.12	2.06
	21 Oct	0913	2.71	2.47
		1412	2.76	2.42
	12 Nov	1508	2.87	2.31
		1607	2.86	2.32
	11 Dec	0850	3.43	1.75
		1110	3.40	1.78
	15 Jan 85	1415	3.14	2.04
		1558	3.27	1.91
	9 Feb	0926	3.34	1.84
		1430	3.31	1.87
		1706	3.38	1.80
		2157	3.50	1.68
	10 Feb	0132	3.54	1.64
		0612	3.55	1.63
	6 Mar	1414	3.66	1.52
		1643	3.75	1.43
	9 Apr	0956	3.11	2.07
		0846	3.07	2.11
	6 May	1544	3.39	1.79
		1824	3.90	1.28

TABLE 3
(continued)
GROUND-WATER LEVEL MEASUREMENTS AT KILL DEVIL HILLS

Well I.D.	Measurement Date	Measurement Time	Depth to water from measuring point (ft)	Water level elevation (MSL)
K2E3	10 Jul 84	1359	3.30	2.16
	17 Aug	0802	3.47	1.99
		1131	3.51	1.95
		1535	3.56	1.90
		2115	3.56	1.90
	18 Aug	0042	3.48	1.98
		0439	3.42	2.04
	18 Sep	0745	3.33	2.13
		0822	3.35	2.11
	21 Oct	0913	2.85	2.61
		1413	2.89	2.57
	12 Nov	1508	3.02	2.44
		1607	3.05	2.41
	11 Dec	0851	3.60	1.86
		1111	3.56	1.90
	15 Jan 85	1415	3.31	2.15
		1558	3.43	2.03
	9 Feb	0927	3.50	1.96
		1430	3.48	1.98
		1707	3.58	1.88
		2158	3.69	1.77
	10 Feb	0134	3.73	1.73
		0613	3.73	1.73
	6 Mar	1414	3.84	1.62
		1644	3.93	1.53
	9 Apr	0957	3.25	2.21
		0847	3.18	2.28
	6 May	1545	3.52	1.94
		1825	3.51	1.95
K3A1	10 Jul 84	1720	10.70	2.88
	17 Aug	0832	10.19	3.39
		1200	10.21	3.37
		1601	10.20	3.38
		2225	10.20	3.38
	18 Aug	0228	10.20	3.38
		0713	10.20	3.38
	17 Sep	1649	9.23	4.35
		1817	9.23	4.35
	19 Oct	1541	8.32	5.26
		1659	8.31	5.27
	12 Nov	1138	9.30	4.28
		1300	9.27	4.31
	10 Dec	1408	10.33	3.25
		1501	10.32	3.26
	15 Jan 85	1358	10.23	3.35
		1622	10.23	3.35
	9 Feb	0940	9.57	4.01
		1443	9.50	3.98
		1723	9.62	3.96
		2214	9.65	3.93
	10 Feb	0147	9.66	3.92
		0630	9.52	4.06
	6 Mar	1457	10.24	3.34
		1716	10.24	3.34
	10 Apr	0818	10.37	3.21
		1108	10.38	3.20
	6 May	1625	10.18	3.40
		1839	10.20	3.38

TABLE 3
(continued)
GROUND-WATER LEVEL MEASUREMENTS AT KILL DEVIL HILLS

Well I.D.	Measurement Date	Measurement Time	Depth to water from measuring point (ft)	Water level elevation (MSL)
K3A2	10 Jul 84	1724	10.60	2.93
	17 Aug	0834	10.12	3.41
		1201	10.12	3.41
		1602	10.11	3.42
		2227	10.14	3.39
	18 Aug	0226	10.12	3.41
		0714	10.12	3.41
	17 Sep	1647	9.12	4.41
		1816	9.12	4.41
	19 Oct	1542	8.25	5.28
		1700	8.24	5.29
	12 Nov	1133	9.19	4.34
		1259	9.18	4.35
	10 Dec	1409	10.24	3.29
		1502	10.23	3.30
	15 Jan 85	1447	10.14	3.39
		1623	10.13	3.40
	9 Feb	0941	9.48	4.05
		1444	9.52	4.01
		1724	9.54	3.99
		2216	9.58	3.95
	10 Feb	0149	9.59	3.94
		0632	9.59	3.94
	6 Mar	1456	10.15	3.38
		1717	10.14	3.39
	10 Apr	0818	10.29	3.24
		1109	10.30	3.23
	6 May	1626	10.11	3.42
		1839	10.13	3.40
K3A2B	10 Jul 84	1729	9.98	2.96
	17 Aug	0832	9.50	3.44
		1201	9.47	3.47
		1604	9.48	3.46
		2228	9.50	3.44
	18 Aug	0224	9.49	3.45
		0715	9.51	3.43
	17 Sep	1643	8.48	4.46
		1815	8.49	4.45
	19 Oct	1543	7.65	5.29
		1701	7.63	5.31
	12 Nov	1136	8.55	4.39
		1258	8.55	4.39
	10 Dec	1411	9.60	3.34
		1503	9.60	3.34
	15 Jan 85	1448	9.50	3.44
		1624	9.51	3.43
	9 Feb	0942	8.87	4.07
		1444	8.91	4.03
		1725	8.95	3.99
		2218	8.96	3.98
	10 Feb	0151	8.94	4.00
		0633	9.28	3.97
	6 Mar	1453	9.52	3.42
		1719	9.49	3.45
	10 Apr	0819	9.67	3.27
		1109	9.67	3.27
	6 May	1627	9.56	3.38
		1840	9.56	3.38

TABLE 3
(continued)
GROUND-WATER LEVEL MEASUREMENTS AT KILL DEVIL HILLS

Well I.D.	Measurement Date	Measurement Time	Depth to water from measuring point (ft)	Water level elevation (MSL)
K3A3B	10 Jul 84	1731	10.14	3.03
	17 Aug	0835	9.75	3.42
		1203	9.65	3.52
		1605	9.69	3.48
		2230	9.69	3.48
	18 Aug	0225	9.66	3.51
		0716	9.71	3.46
	17 Sep	1645	8.70	4.47
		1816	8.75	4.42
	19 Oct	1544	7.90	5.27
		1702	7.87	5.30
	12 Nov	1137	8.62	4.55
		1258	8.67	4.50
	10 Dec	1410	9.85	3.32
		1503	9.87	3.30
	15 Jan 85	1449	9.67	3.50
		1625	9.69	3.48
	9 Feb	0943	9.08	4.09
		1445	9.25	3.92
		1726	9.33	3.84
		2220	9.14	4.03
	10 Feb	0153	9.17	4.00
		0635	9.28	3.89
	6 Mar	1455	9.78	3.39
		1718	9.64	3.53
	10 Apr	0819	9.94	3.23
		1110	9.86	3.31
	6 May	1627	10.00	3.17
		1841	9.92	3.25
K3B1	11 Jul 84	1500	3.85	6.44
	17 Aug	0842	3.98	6.31
		1207	3.99	6.30
		1612	3.99	6.30
		2237	4.00	6.29
	18 Aug	0217	4.01	6.28
		0655	4.01	6.28
	17 Sep	1658	2.42	7.87
		1809	2.44	7.85
	19 Oct	1557	3.48	6.81
		1731	3.48	6.81
	12 Nov	1143	3.24	7.05
		1313	3.25	7.04
	10 Dec	1415	3.46	6.83
		1519	3.46	6.83
	15 Jan 85	1456	3.87	6.42
		1629	3.87	6.42
	9 Feb	0958	3.27	7.02
		1450	3.26	7.03
		1728	3.28	7.01
		2225	3.30	6.99
	10 Feb	0200	3.33	6.96
		0645	3.33	6.96
	6 Mar	1501	3.32	6.97
		1724	3.32	6.97
	10 Apr	0846	3.83	6.46
		1125	3.83	6.46
	6 May	1637	4.30	5.99
		1845	4.30	5.99

TABLE 3
(continued)
GROUND-WATER LEVEL MEASUREMENTS AT KILL DEVIL HILLS

Well I.D.	Measurement Date	Measurement Time	Depth to water from measuring point (ft)	Water level elevation (MSL)
K3C1	10 Jul 84	1652	4.28	9.69
	17 Aug	0847	4.53	9.44
		1218	4.55	9.42
		1553	4.55	9.42
		2326	4.57	9.40
	18 Aug	0213	4.57	9.40
		0650	4.57	9.40
	17 Sep	1703	3.21	10.76
		1806	3.21	10.76
	19 Oct	1605	4.31	9.66
		1733	4.31	9.66
	12 Nov	1148	4.44	9.53
		1318	4.43	9.54
	10 Dec	1419	4.49	9.48
		1529	4.49	9.48
	15 Jan 85	1459	4.90	9.07
		1633	4.90	9.07
	9 Feb	1002	4.29	9.68
		1453	4.30	9.67
		1731	4.31	9.66
		2228	4.31	9.66
	10 Feb	0204	4.33	9.64
		0648	4.33	9.64
	6 Mar	1506	4.15	9.82
		1727	4.16	9.81
	10 Apr	0855	4.54	9.43
		1128	4.54	9.43
	6 May	1644	5.11	8.86
		1848	5.11	8.86
K3D1	11 Jul 84	1511	5.18	10.56
	17 Aug	0855	5.36	10.38
		1258	5.38	10.36
		1614	5.34	10.40
		2321	5.41	10.33
	18 Aug	0206	5.41	10.33
		0642	5.41	10.33
	17 Sep	1545	4.11	11.63
		1749	4.12	11.62
	19 Oct	1610	5.29	10.45
	12 Nov	1153	5.49	10.25
		1325	5.48	10.26
	10 Dec	1424	5.61	10.13
		1535	5.60	10.14
	15 Jan 85	1505	6.07	9.67
	9 Feb	1009	5.40	10.34
	6 Mar	1521	5.22	10.52
		1738	5.22	10.52
	10 Apr	0905	5.63	10.11
	6 May	1656	6.26	9.48
		1853	6.23	9.51

TABLE 3
(continued)
GROUND-WATER LEVEL MEASUREMENTS AT KILL DEVIL HILLS

Well I.D.	Measurement Date	Measurement Time	Depth to water from measuring point (ft)	Water level elevation (MSL)
K3D2	11 Jul 84	1512	6.62	10.71
	17 Aug	0902	9.26	8.07
		1224	9.25	8.08
		1610	9.28	8.05
		2315	9.27	8.06
	18 Aug	0202	9.29	8.04
		0639	9.29	8.04
	17 Sep	1600	8.17	9.16
		1747	8.06	9.27
	19 Oct	1614	9.08	8.25
		1737	9.10	8.23
	12 Nov	1159	9.32	8.01
		1323	9.31	8.02
	10 Dec	1427	9.27	8.06
		1546	9.27	8.06
	15 Jan 85	1505	9.75	7.58
		1635	9.78	7.55
	9 Feb	1017	9.17	8.16
		1459	9.16	8.17
		1735	9.18	8.15
		2239	9.17	8.16
	10 Feb	0207	9.20	8.13
		0653	9.21	8.12
	6 Mar	1519	9.12	8.21
		1736	9.12	8.21
	10 Apr	0905	9.57	7.76
		1132	9.56	7.77
	6 May	1658	10.02	7.31
		1852	10.04	7.29
K3D3B	10 Jul 84	1544	6.87	7.81
	17 Aug	0905	7.04	7.64
		1222	7.05	7.63
		1611	7.07	7.61
		2318	7.07	7.61
	18 Aug	0203	7.08	7.60
		0640	7.09	7.59
	17 Sep	1604	5.84	8.84
		1750	5.85	8.83
	19 Oct	1616	6.83	7.85
		1738	6.84	7.84
	12 Nov	1200	7.05	7.63
		1325	7.03	7.65
	10 Dec	1428	7.00	7.68
		1547	7.00	7.68
	15 Jan 85	1506	7.42	7.26
		1637	7.44	7.24
	9 Feb	1018	6.83	7.85
		1458	6.84	7.84
		1736	6.83	7.85
		2236	6.84	7.84
	10 Feb	0209	6.89	7.79
		0654	6.86	7.82
	6 Mar	1520	6.79	7.89
		1741	6.80	7.88
	10 Apr	0906	7.21	7.47
		1130	7.22	7.46
	6 May	1657	7.69	6.99
		1854	7.68	7.00

TABLE 3
(continued)
GROUND-WATER LEVEL MEASUREMENTS AT KILL DEVIL HILLS

Well I.D.	Measurement Date	Measurement Time	Depth to water from measuring point (ft)	Water level elevation (MSL)
K3E1	11 Jul 84	1521	4.43	8.61
	17 Aug	0912	4.59	8.45
		1229	4.59	8.45
		1604	4.61	8.43
		2304	4.62	8.42
	18 Aug	0155	4.62	8.42
		0557	4.65	8.39
	17 Sep	1615	3.42	9.62
		1741	3.40	9.64
	19 Oct	1628	4.57	8.47
		1742	4.57	8.47
	12 Nov	1209	4.92	8.12
		1400	4.92	8.12
	10 Dec	1433	4.82	8.22
		1558	4.82	8.22
	15 Jan 85	1510	5.29	7.75
		1640	5.30	7.74
	9 Feb	1025	4.67	8.37
		1504	4.66	8.38
		1740	4.66	8.38
		2244	4.68	8.36
	10 Feb	0216	4.66	8.38
		0704	4.66	8.38
	6 Mar	1512	4.45	8.59
		1731	4.45	8.59
	10 Apr	0942	4.90	8.14
		1139	4.91	8.13
	6 May	1710	5.50	7.54
		1900	5.50	7.54
K3F1	10 Jul 84	1610	6.76	6.19
	17 Aug	0920	6.87	6.08
		1223	6.89	6.06
		1558	6.91	6.04
		2255	6.89	6.06
	18 Aug	0145	6.90	6.05
		0550	6.90	6.05
	17 Sep	1623	6.10	6.85
		1758	6.10	6.85
	19 Oct	1652	6.74	6.21
		1751	6.74	6.21
	12 Nov	1218	6.84	6.11
		1339	6.85	6.10
	10 Dec	1441	6.76	6.19
		1608	6.76	6.19
	15 Jan 85	1520	7.05	5.90
		1648	7.05	5.90
	9 Feb	1035	6.47	6.48
		1510	6.49	6.46
		1748	6.49	6.46
		2254	6.51	6.44
	10 Feb	0225	6.51	6.44
		0713	6.50	6.45
	6 Mar	1532	6.53	6.42
		1748	6.53	6.42
	10 Apr	0957	6.88	6.07
		1144	6.88	6.07
	6 May	1717	7.52	5.43
		1908	7.52	5.43

TABLE 3
(continued)
GROUND-WATER LEVEL MEASUREMENTS
AT KILL DEVIL HILLS

Well I.D.	Measurement Date	Measurement Time	Depth to water from measuring point (ft)	Water level elevation (MSL)
K3G1	10 Jul 84	1624	4.65	1.82
	17 Aug	0919	4.63	1.84
		1214	4.66	1.81
		1550	4.68	1.79
		2246	4.66	1.81
	18 Aug	0138	4.64	1.83
		0539	4.65	1.82
	17 Sep	1630	4.37	2.10
		1800	4.37	2.10
	19 Oct	1644	4.41	2.06
		1748	4.41	2.06
	12 Nov	1222	4.41	2.06
		1345	4.40	2.07
	10 Dec	1445	4.52	1.95
		1614	4.51	1.96
	15 Jan 85	1523	4.53	1.94
		1651	4.55	1.92
	9 Feb	1038	4.43	2.04
		1512	4.43	2.04
		1752	4.44	2.03
		2256	4.46	2.01
	10 Feb	0228	4.48	1.99
		0715	4.47	2.00
	6 Mar	1537	4.57	1.90
		1752	4.57	1.90
	10 Apr	1004	4.70	1.77
		1146	4.71	1.76
	6 May	1724	4.78	1.69
		1911	4.77	1.70
K3G2	10 Jul 84	1627	4.36	2.16
	17 Aug	0920	4.41	2.11
		1215	4.45	2.07
		1551	4.47	2.05
		2247	4.45	2.07
	18 Aug	0140	4.42	2.10
		0540	4.40	2.12
	17 Sep	1632	4.06	2.46
		1801	4.07	2.45
	19 Oct	1644	4.06	2.46
		1749	4.06	2.46
	12 Nov	1222	4.06	2.46
		1345	4.05	2.47
	10 Dec	1447	4.29	2.23
		1615	4.29	2.23
	15 Jan 85	1523	4.24	2.28
		1652	4.28	2.24
	9 Feb	1039	4.02	2.50
		1513	4.12	2.40
		1753	4.17	2.35
		2257	4.19	2.33
	10 Feb	0229	4.26	2.26
		0716	4.23	2.29
	6 Mar	1538	4.41	2.11
		1753	4.44	2.08
	10 Apr	1005	4.58	1.94
		1146	4.58	1.94
	6 May	1725	4.61	1.91
		1912	4.61	1.91

TABLE 3
(continued)
GROUND-WATER LEVEL MEASUREMENTS AT KILL DEVIL HILLS

Well I.D.	Measurement Date	Measurement Time	Depth to water from measuring point (ft)	Water level elevation (MSL)
K3G3	10 Jul 84	1630	4.23	2.25
	17 Aug	0923	4.29	2.19
		1216	4.32	2.16
		1553	4.35	2.13
		2249	4.32	2.16
	18 Aug	0142	4.30	2.18
		0542	4.28	2.20
	17 Sep	1635	3.95	2.53
		1802	3.95	2.53
	19 Oct	1644	3.92	2.56
		1749	3.90	2.58
	12 Nov	1223	3.92	2.56
		1346	3.89	2.59
	10 Dec	1448	4.19	2.29
		1616	4.19	2.29
	15 Jan 85	1523	4.12	2.36
		1652	4.17	2.31
	9 Feb	1040	4.00	2.48
		1514	4.01	2.47
		1754	4.06	2.42
		2259	4.10	2.38
	10 Feb	0230	4.11	2.37
		0718	4.13	2.35
	6 Mar	1538	4.34	2.14
		1753	4.36	2.12
	10 Apr	1005	4.51	1.97
		1147	4.50	1.98
	6 May	1726	4.49	1.99
		1912	4.47	2.01

WATER-LEVEL DATA
FOR
ATLANTIC BEACH

TABLE 1

ATLANTIC OCEAN TIDAL MEASUREMENTS AT ATLANTIC BEACH

Measurement Date	Measurement Time	Depth to water from measuring point (ft)	Water level elevation (MSL)
14 Jul 84	1005	13.95	2.94
19 Aug	0707	17.73	-0.84
	1121	15.13	1.76
	1516	15.25	1.64
	1925	16.99	-0.10
	2320	15.77	1.12
20 Aug	0315	16.03	0.86
	0733	17.66	-0.77
17 Sep	0900	16.00	0.89
	1318	13.92	2.97
18 Oct	0846	17.10	-0.21
	1157	14.48	2.41
11 Nov	0820	11.05	5.84
	1142	12.95	3.94
	1628	14.95	1.94
12 Dec	0748	14.46	2.43
	1202	14.90	1.99
	1505	17.70	-0.81
18 Jan 85	1535	14.10	2.79
	1710	14.04	2.85
11 Feb	0850	16.62	0.27
	1238	15.43	1.46
	1635	18.27	-1.38
	2045		0.2[a]
12 Feb	0030		2.6[a]
	0720	19.44	-2.55
8 Mar	1251	16.13	0.76
11 Apr	0805	18.05	-1.16
	0905	17.29	-0.40
12 Apr	0917	17.74	-0.85
	1218	16.08	0.81
7 May	1306	16.92	-0.03
	1638	18.73	-1.84

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[a] Estimated from tidal tables (NOAA, 1985)

TABLE 2

BOGUE SOUND TIDAL MEASUREMENTS AT ATLANTIC BEACH

Measurement Date	Measurement Time	Staff gauge reading (ft)	Water level elevation (MSL)
14 Jul 84	1420	0.94	-0.92
19 Aug	0825	1.43	-0.43
	1110	2.85	0.99
	1501	3.66	1.80
	1906	2.13	0.27
	2310	2.68	0.82
20 Aug	0307	3.10	1.24
	0726	1.57	-0.29
17 Sep	0922	5.29	3.43
	1328	4.52	2.66
18 Oct	0808	1.76	-0.10
	1103	2.64	0.78
11 Nov	0842	4.74	2.88
	1149	3.34	1.48
	1640	1.74	-0.12
12 Dec	0757	3.74	1.61
	1211	3.90	2.04
	1539	1.74	-0.12
18 Jan 85	1553	3.22	1.36
	1728	4.13	2.27
11 Feb	0920	1.98	0.12
	1315	3.30	1.44
	1702	1.29	-0.57
	2115	2.50	0.64
12 Feb	0040	4.90	3.04
	0628	0.57	-1.29
8 Mar	1259	2.90	1.04
	1811	4.44	2.58
11 Apr	0835	0.89	-0.97
	0930	1.59	-0.27
12 Apr	0930	0.68	-1.18
	1230	2.26	0.40
7 May	1339	2.15	0.29
	1651	0.60	-1.26

TABLE 3

GROUND-WATER LEVEL MEASUREMENTS AT ATLANTIC BEACH

Well I.D.	Measurement Date	Measurement Time	Depth to water from measuring point (ft)	Water level elevation (MSL)
A1A1	14 Jul 84	0950	6.88	3.80
	19 Aug	0652	7.95	2.73
		1052	7.97	2.71
		1443	7.96	2.72
		1853	7.93	2.75
		2253	8.01	2.67
	20 Aug	0244	8.01	2.67
		0658	8.04	2.64
	17 Sep	0917	5.97	4.71
		1512	5.97	4.71
	18 Oct	0831	7.12	3.56
		0935	7.13	3.55
	11 Nov**	0916	7.45	3.23
		1040	7.39	3.29
	12 Dec	1234	7.86	2.82
		1512	7.96	2.72
	18 Jan 85	1542	7.69	2.99
		1717	7.65	3.03
	11 Feb	0906	7.56	3.03
		1250	7.64	3.04
		1643	7.68	3.00
		2059	7.70	2.98
	12 Feb	0017	7.59	3.09
		0615	7.20	3.48
	8 Mar	1317	7.82	2.86
		1533	7.85	2.83
	11 Apr	0819	7.71	2.97
		0909	8.08	2.60
	7 May	1317	7.77	2.91
		1655	7.84	2.84
A1A3	14 Jul 84	0955	8.04	2.58
	19 Aug	0653	9.48	1.14
		1051	8.44	2.18
		1442	7.90	2.72
		1854	8.97	1.65
		2255	8.79	1.83
	20 Aug	0242	8.33	2.29
		0659	9.37	1.25
	17 Sep	0916	7.76	2.86
		1512	7.06	3.56
	18 Oct	0832	8.94	1.68
		0935	8.75	1.87
	11 Nov**	0915	7.07	3.55
		1040	7.41	3.21
	12 Dec	1235	8.21	2.41
		1513	9.39	1.23
	18 Jan 85	1542	8.21	2.41
		1717	7.85	2.77
	11 Feb	0907	8.78	1.84
		1251	7.99	2.63
		1644	9.43	1.19
		2059	8.55	2.07
	12 Feb	0018	6.70	3.92
		0616	9.04	1.58
	8 Mar	1316	10.01	0.61
		1533	10.05	0.57
	11 Apr	0820	8.07	2.55
		0910	8.39	2.23
	7 May	1317	9.01	1.61
		1656	9.01	1.61

TABLE 3
(continued)
GROUND-WATER LEVEL MEASUREMENTS AT ATLANTIC BEACH

Well I.D.	Measurement Date	Measurement Time	Depth to water from measuring point (ft)	Water level elevation (MSL)
A1B1	14 Jul 84	0940	4.08	4.67
	19 Aug	0647	4.94	3.81
		1056	5.85	3.90
		1445	4.86	3.89
		1857	4.86	3.89
		2247	4.89	3.86
	20 Aug	0249	4.91	3.84
		0705	4.88	3.87
	17 Sep	0913	2.03	6.72
		1445	2.07	6.68
	18 Oct	0821	4.12	4.63
		1007	4.12	4.63
	11 Nov**	0907	4.81	3.94
		1031	4.79	3.96
	12 Dec	1227	5.07	3.68
		1522	5.09	3.66
	18 Jan 85	1545	5.44	3.31
		1720	5.44	3.31
	11 Feb	0912	4.43	4.32
		1302	4.44	4.31
		1647	4.45	4.30
		2103	4.43	4.32
	12 Feb	0025	4.43	4.32
		0622	3.10	5.65
	8 Mar	1312	4.84	3.91
		1525	4.82	3.93
	11 Apr	0822	5.00	3.75
		0920	5.00	3.75
	7 May	1323	5.64	3.11
		1658	5.64	3.11
A1B3	14 Jul 84	0938	4.97	3.71
	19 Aug	0648	6.26	2.42
		1057	5.90	2.78
		1446	5.56	3.12
		1858	6.03	2.65
		2248	6.02	2.66
	20 Aug	0251	5.77	2.91
		0706	6.24	2.44
	17 Sep	0914	4.48	4.20
		1445	3.94	4.74
	18 Oct	0822	5.76	2.92
		1007	5.67	3.01
	11 Nov**	0907	5.18	3.50
		1031	5.22	3.46
	12 Dec	1229	5.76	2.92
		1523	6.39	2.29
	18 Jan 85	1545	6.11	2.57
		1721	5.89	2.79
	11 Feb	0913	6.01	2.67
		1304	5.55	3.13
		1648	6.14	2.54
		2103	5.90	2.78
	12 Feb	0026	5.03	3.65
		0623	5.72	2.96
	8 Mar	1313	6.57	2.11
		1525	6.75	1.93
	11 Apr	0823	6.62	2.06
		0921	6.51	2.17
	7 May	1323	6.38	2.30
		1659	6.95	1.73

TABLE 3
(continued)
GROUND-WATER LEVEL MEASUREMENTS
AT ATLANTIC BEACH

Well I.D.	Measurement Date	Measurement Time	Depth to water from measuring point (ft)	Water level elevation (MSL)
A1C1	14 Jul 84	0930	6.78	4.35
	19 Aug	0642	7.32	3.81
		1101	7.33	3.80
		1451	7.35	3.78
		1901	7.35	3.78
		2241	7.37	3.76
	20 Aug	0256	7.41	3.72
		0710	7.38	3.75
	17 Sep	0909	5.06	6.07
		1418	5.09	6.04
	18 Oct	0813	6.78	4.35
		1037	6.78	4.35
	11 Nov**	0900	7.49	3.64
		1023	7.49	3.64
	12 Dec	1222	7.67	3.46
		1531	7.68	3.45
	18 Jan 85	1548	8.11	3.02
		1723	8.11	3.02
	11 Feb	0917	7.04	4.09
		1313	7.03	4.10
		1653	7.05	4.08
		2105	7.06	4.07
	12 Feb	0028	7.02	4.11
		0627	6.94	4.19
	8 Mar	1308	7.49	3.64
		1518	7.49	3.64
	11 Apr	0825	7.62	3.51
		0923	7.62	3.51
	7 May	1328	8.23	2.90
		1702	8.25	2.88
A1C3	14 Jul 84	0930	5.82	5.16
	19 Aug	0643	7.67	3.31
		1102	7.63	3.35
		1452	7.56	3.42
		1902	7.64	3.34
		2242	7.67	3.31
	20 Aug	0257	7.61	3.38
		0711	7.68	3.30
	17 Sep	0910	5.80	5.18
		1417	5.69	5.29
	18 Oct	0812	7.17	3.81
		1038	7.17	3.81
	11 Nov**	0901	7.46	3.52
		1022	7.45	3.53
	12 Dec	1223	7.81	3.17
		1532	7.94	3.04
	18 Jan 85	1550	8.14	2.84
		1724	8.09	2.89
	11 Feb	0918	7.48	3.50
		1314	7.36	3.62
		1655	7.48	3.50
		2106	7.49	3.49
	12 Feb	0029	7.29	3.69
		0627	6.99	3.99
	8 Mar	1309	7.87	3.11
		1517	7.94	3.04
	11 Apr	0826	8.02	2.96
		0924	8.01	2.97
	7 May	1328	8.32	2.66
		1703	8.46	2.52

TABLE 3
(continued)
GROUND-WATER LEVEL MEASUREMENTS AT ATLANTIC BEACH

Well I.D.	Measurement Date	Measurement Time	Depth to water from measuring point (ft)	Water level elevation (MSL)
A1D1	14 Jul 84	0854	2.42	2.56
	19 Aug	0828	1.95	3.03
		1107	2.67	2.31
		1456	2.33	2.65
		1906	2.67	2.31
		2305	2.72	2.26
	20 Aug	0303	2.49	2.49
		0720	2.89	2.09
	17 Sep	0925	1.72	3.26
		1326	1.29	3.69
	18 Oct	0800	2.56	2.42
		1105	2.45	2.53
	11 Nov**	0848	1.99	2.99
		1008	1.94	3.04
	12 Dec	1216	2.52	2.46
		1541	3.01	1.97
	18 Jan 85	1554	2.74	2.24
		1728	2.57	2.41
	11 Feb	0925	2.82	2.16
		1317	2.45	2.53
		1659	2.89	2.09
		2111	2.80	2.18
	12 Feb	0032	2.17	2.81
		0632	1.79	3.19
	8 Mar	1302	3.23	1.75
		1506	3.50	1.48
	11 Apr	0830	3.28	1.70
		0927	3.21	1.77
	7 May	1334	3.04	1.94
		1648	3.45	1.53
A1D2	14 Jul 84	0852	2.18	2.64
	19 Aug	0829	2.66	2.16
		1108	2.44	2.38
		1457	2.12	2.70
		1905	2.43	2.39
		2306	2.40	2.42
	20 Aug	0305	2.26	2.56
		0721	2.62	2.20
	17 Sep	0925	1.48	3.34
		1327	1.06	3.76
	18 Oct	0801	2.26	2.56
		1106	2.18	2.64
	11 Nov**	0848	1.69	3.13
		1008	1.71	3.11
	12 Dec	1217	2.31	2.51
		1542	2.78	2.04
	18 Jan 85	1554	2.53	2.29
		1729	2.35	2.47
	11 Feb	0927	2.59	2.23
		1317	2.24	2.58
		1659	2.66	2.13
		2111	2.57	2.25
	12 Feb	0033	1.96	2.86
		0633		a
	8 Mar	1303	2.97	1.85
		1507	3.23	1.59
	11 Apr	0830	3.04	1.78
		0928	2.97	1.85
	7 May	1335	2.71	2.11
		1649	3.22	1.60

TABLE 3
(continued)
GROUND-WATER LEVEL MEASUREMENTS
AT ATLANTIC BEACH

Well I.D.	Measurement Date	Measurement Time	Depth to water from measuring point (ft)	Water level elevation (MSL)
A1D3	14 Jul 84	0851	2.66	2.40
	19 Aug	0829	3.01	2.05
		1109	2.79	2.27
		1458	2.50	2.56
		1904	2.79	2.27
		2307	2.79	2.27
	20 Aug	0306	2.64	2.42
		0722	2.98	2.08
	17 Sep	0926	1.87	3.19
		1327	1.45	3.61
	18 Oct	0801	2.51	2.55
		1106	2.43	2.63
	11 Nov**	0849	2.10	2.96
		1007	2.05	3.01
	12 Dec	1218	2.60	2.46
		1543	3.05	2.01
	18 Jan 85	1555	2.76	2.30
		1729	2.60	2.46
	11 Feb	0928	3.03	2.03
		1318	2.72	2.34
		1700	3.11	1.95
		2112	3.02	2.04
	12 Feb	0034	2.45	2.61
		0634	1.92	3.14
	8 Mar	1304	3.10	1.96
		1507	3.27	1.79
	11 Apr	0831	3.18	1.88
		0929	3.13	1.93
	7 May	1335	3.24	1.82
		1649	3.56	1.50
A2A1	14 Jul 84	1021	6.70	3.42
	19 Aug	0640	6.97	3.15
		1142	7.00	3.12
		1531	6.95	3.17
		1934	6.93	3.19
		2348	7.02	3.10
	20 Aug	0326	6.99	3.13
		0751	7.03	3.09
	17 Sep	0845	5.36	4.76
		1134	5.40	4.72
	18 Oct	0856	6.56	3.56
		1522	6.54	3.58
	11 Nov**	0952	6.70	3.42
		1124	6.66	3.46
	12 Dec	1242	7.26	2.86
		1606	7.25	2.87
	18 Jan 85	1601	7.21	2.91
		1736	7.17	2.95
	11 Feb	0933	7.14	2.98
		1326	7.13	2.99
		1708	7.17	2.95
		2120	7.22	2.90
	12 Feb	0043	7.09	3.03
		0647	6.80	3.32
	8 Mar	1342	7.32	2.80
		1607	7.43	2.69
	11 Apr	0840	7.46	2.66
		0934	7.47	2.65
	7 May	1346	7.16	2.96
		1706	7.24	2.88

TABLE 3
(continued)
GROUND-WATER LEVEL MEASUREMENTS AT ATLANTIC BEACH

Well I.D.	Measurement Date	Measurement Time	Depth to water from measuring point (ft)	Water level elevation (MSL)
A2A3	14 Jul 84	1022	7.02	3.06
	19 Aug	0643	7.63	2.45
		1143	7.82	2.26
		1528	10.73	-0.65
		1936	10.98	-0.90
		2351	10.97	-0.89
	20 Aug	0325	10.94	-0.86
		0752	11.14	-1.06
	17 Sep	0848	6.13	3.95
		1135	5.87	4.21
	18 Oct	0857	6.99	3.09
		1523	6.41	3.67
	11 Nov**	0953	6.29	3.79
		1125	6.57	3.51
	12 Dec	1243	7.28	2.80
		1606	7.51	2.57
	18 Jan 85	1603	7.03	3.05
		1737	6.97	3.11
	11 Feb	0934	7.48	2.60
		1327	7.33	2.75
		1709	7.66	2.42
		2121	7.45	2.63
	12 Feb	0045	6.42	3.66
		0648	7.13	2.95
	8 Mar	1341	7.86	2.22
		1606	7.92	2.16
	11 Apr	0841	7.83	2.25
		0935	7.82	2.26
	7 May	1347	7.44	2.64
		1707	7.69	2.39
A2A4	14 Jul 84	1023	8.72	1.20
	19 Aug	0642	7.35	2.57
		1144	7.23	2.69
		1529	6.97	2.95
		1938	7.18	2.74
		2352	9.24	0.68
	20 Aug	0328	7.18	2.74
		0753	7.39	2.53
	17 Sep	0847	8.55	1.37
		1134	8.26	1.66
	18 Oct	0857	8.16	1.76
		1524	7.67	2.25
	11 Nov**	0953	7.53	2.39
		1126	7.75	2.17
	12 Dec	1244	8.10	1.82
		1607	8.43	1.49
	18 Jan 85	1602	9.78	0.14
		1737	9.70	0.22
	11 Feb	0935	8.61	1.31
		1327	9.39	0.53
		1710	8.71	1.21
		2122	8.53	1.39
	12 Feb	0046	7.69	2.23
		0649	8.43	1.49
	8 Mar	1340	9.91	0.01
		1605	9.91	0.01
	11 Apr	0842	10.33	-0.41
		0935	10.29	-0.37
	7 May	1347	8.75	1.17
		1708	9.04	0.88

TABLE 3
(continued)
GROUND-WATER LEVEL MEASUREMENTS AT ATLANTIC BEACH

Well I.D.	Measurement Date	Measurement Time	Depth to water from measuring point (ft)	Water level elevation (MSL)
A2B1	14 Jul 84	1037	1.96	4.71
	19 Aug	0650	2.48	4.19
		1150	2.48	4.19
		1536	2.48	4.19
		1942	2.49	4.18
		2337	2.51	4.16
	20 Aug	0333	2.51	4.16
		0800	2.52	4.15
	17 Sep	0839	0.22	6.45
		1046	0.22	6.45
	18 Oct	0907	2.18	4.49
		1412	2.18	4.49
	11 Nov**	0941	2.61	4.06
		1108	2.59	4.08
	12 Dec	1250	2.95	3.72
		1620	2.96	3.71
	18 Jan 85	1606	3.31	3.36
		1740	3.29	3.38
	11 Feb	0939	2.41	4.26
		1337	2.38	4.29
		1715	2.40	4.27
		2125	2.40	4.27
	12 Feb	0052	2.40	4.27
		0655	1.77	4.90
	8 Mar	1333	2.93	3.74
		1555	2.94	3.73
	11 Apr	0848	3.01	3.66
		0938	3.03	3.64
	7 May	1354	3.40	3.27
		1712	3.41	3.26
A2B3	14 Jul 84	1043	2.66	3.94
	19 Aug	0653	3.05	3.55
		1151	3.04	3.56
		1537	3.01	3.59
		1943	3.03	3.57
		2339	3.07	3.53
	20 Aug	0334	3.04	3.56
		0801	3.10	3.50
	17 Sep	0839	1.20	5.40
		1050	1.20	5.40
	18 Oct	0907	2.72	3.88
		1413	2.64	3.96
	11 Nov**	0943	2.95	3.65
		1108	2.95	3.65
	12 Dec	1251	3.41	3.19
		1621	3.47	3.13
	18 Jan 85	1607	3.62	2.98
		1741	3.59	3.01
	11 Feb	0941	3.07	3.53
		1338	3.00	3.60
		1716	5.05	1.55
		2126	3.04	3.56
	12 Feb	0053	2.90	3.70
		0656	2.53	4.07
	8 Mar	1335	3.52	3.08
		1554	3.55	3.05
	11 Apr	0847	3.56	3.04
		0939	3.57	3.03
	7 May	1356	3.72	2.88
		1712	3.77	2.83

TABLE 3
(continued)
GROUND-WATER LEVEL MEASUREMENTS AT ATLANTIC BEACH

Well I.D.	Measurement Date	Measurement Time	Depth to water from measuring point (ft)	Water level elevation (MSL)
A2B4	14 Jul 84	1040	6.62	0.13
	19 Aug	0652	6.75	0.00
		1152	6.76	-0.01
		1540	6.71	0.04
		1945	6.76	-0.01
		2340	6.84	-0.09
	20 Aug	0335	6.81	-0.06
		0802	6.88	-0.13
	17 Sep	0838	4.86	1.89
		1048	4.83	1.92
	18 Oct	0908	4.28	2.47
		1414	4.21	2.54
	11 Nov**	0942	4.32	2.43
		1109	4.32	2.43
	12 Dec	1251	4.63	2.12
		1621	4.73	2.02
	18 Jan 85	1607	5.67	1.08
		1741	5.66	1.09
	11 Feb	0943	5.01	1.74
		1339	5.00	1.75
		1718	3.08	3.67
		2127	4.99	1.76
	12 Feb	0054	4.81	1.94
		0658	4.68	2.07
	8 Mar	1334	5.80	0.95
		1554	5.82	0.93
	11 Apr	0847	6.04	0.71
		0940	6.04	0.71
	7 May	1355	5.12	1.63
		1713	5.20	1.55
A2C1	14 Jul 84	1055	1.99	2.46
	19 Aug	0702	2.43	2.02
		1158	1.86	2.59
		1544	2.19	2.26
		1948	2.34	2.11
		2328	2.41	2.04
	20 Aug	0340	2.27	2.18
		0741	2.44	2.01
	17 Sep	0826	1.02	3.43
		0953	1.05	3.40
	18 Oct	0921	2.06	2.39
		1207	1.98	2.47
	11 Nov**	0934	1.51	2.94
		1054	1.41	3.04
	12 Dec	1258	1.83	2.62
		1630	2.09	2.36
	18 Jan 85	1612	1.96	2.49
		1743	1.87	2.58
	11 Feb	0945	1.81	2.64
		1348	1.56	2.89
		1721	1.73	2.72
		2132	1.75	2.70
	12 Feb	0058	1.40	3.05
		0703	0.22	4.23
	8 Mar	1324	2.22	2.23
		1542	2.35	2.10
	11 Apr	0851	2.58	1.87
		0943	2.58	1.87
	7 May	1402	2.43	2.02
		1715	2.65	1.80

TABLE 3
(continued)
GROUND-WATER LEVEL MEASUREMENTS AT ATLANTIC BEACH

Well I.D.	Measurement Date	Measurement Time	Depth to water from measuring point (ft)	Water level elevation (MSL)
A2C3	14 Jul 84	1057	2.24	2.37
	19 Aug	0700	2.95	1.66
		1159	2.42	2.19
		1545	2.17	2.44
		1947	2.72	1.89
		2330	2.60	2.01
	20 Aug	0342	2.42	2.19
		0742	2.94	1.67
	17 Sep	0825	1.84	2.77
		0954	1.69	2.92
	18 Oct	0921	2.60	2.01
		1207	2.16	2.45
	11 Nov**	0935	1.61	3.00
		1054	1.58	3.03
	12 Dec	1258	2.20	2.41
		1631	2.93	1.68
	18 Jan 85	1612	2.43	2.18
		1744	2.23	2.38
	11 Feb	0946	2.55	2.06
		1348	2.13	2.48
		1722	2.80	1.81
		2133	2.46	2.15
	12 Feb	0059	1.50	3.11
		0704	1.84	2.77
	8 Mar	1324	3.18	1.43
		1542	3.51	1.10
	11 Apr	0851	3.36	1.25
		0944	3.21	1.40
	7 May	1403	2.94	1.67
		1716	3.49	1.12
A2C4	14 Jul 84	1059	3.78	0.78
	19 Aug	0703	3.81	0.75
		1200	3.73	0.83
		1546	3.63	0.93
		1949	3.77	0.79
		2331	3.79	0.77
	20 Aug	0343	3.74	0.82
		0743	3.88	0.68
	17 Sep	0824	2.70	1.86
		0954	2.69	1.87
	18 Oct	0922	2.26	2.30
		1208	2.16	2.40
	11 Nov**	0935	2.18	2.38
		1054	2.15	2.41
	12 Dec	1300	2.60	1.96
		1631	2.70	1.86
	18 Jan 85	1613	2.99	1.57
		1745	2.95	1.61
	11 Feb	0947	2.76	1.80
		1349	2.74	1.82
		1723	2.81	1.75
		2134	2.84	1.72
	12 Feb	0100	2.54	2.02
		0705	1.90	2.66
	8 Mar	1325	3.27	1.29
		1543	3.36	1.20
	11 Apr	0852	3.33	1.23
		0945	3.30	1.26
	7 May	1404	3.12	1.44
		1716	3.25	1.31

**These measurements were made using an electric water-level indicator.

WATER-LEVEL DATA
FOR
PINE KNOLL SHORES

TABLE 1

GROUND-WATER LEVEL MEASUREMENTS AT PINE KNOLL SHORES

Well I.D.	Measurement Date	Measurement Time	Depth to water from measuring point (ft)	Water level elevation (MSL)
P1A1	14 Jul 84	1220	11.57	3.68
	19 Aug	0725	10.99	4.26
		1137	11.03	4.22
		1455	10.99	4.26
		1935	10.96	4.29
	20 Aug	0005	11.04	4.21
		0433	11.03	4.22
		0903	11.08	4.17
	18 Sep	1045	9.92	5.33
		1236	9.92	5.33
	17 Oct	1352	10.14	5.11
		1509	10.11	5.14
	11 Nov**	1351	10.29	4.96
		1535	10.27	4.98
	12 Dec	0808	11.56	3.69
		0948	11.50	3.75
	18 Jan 85	1438	11.25	4.00
		1622	11.21	4.04
	11 Feb	1000	11.20	4.05
		1402	11.15	4.10
		1739	11.17	4.08
		2142	11.22	4.03
	12 Feb	0110	11.00	4.25
		0746	10.55	4.70
	8 Mar	1358	11.25	4.00
		1623	11.29	3.96
	12 Apr	0947	11.67	3.58
		1125	11.77	3.48
	7 May	1457	11.16	4.09
		1725	11.21	4.04
P1A2	14 Jul 84	1218	11.62	3.66
	19 Aug	0726	11.04	4.24
		1138	11.09	4.19
		1456	11.04	4.24
		1937	11.01	4.27
	20 Aug	0007	11.17	4.11
		0434	11.08	4.20
		0904	11.14	4.14
	18 Sep	1046	9.98	5.30
		1237	9.96	5.32
	17 Oct	1353	10.18	5.10
		1510	10.15	5.13
	11 Nov**	1352	10.33	4.95
		1536	10.32	4.96
	12 Dec	0814	11.60	3.68
		0950	11.54	3.74
	18 Jan 85	1439	11.30	3.98
		1623	11.26	4.02
	11 Feb	1001	11.28	4.00
		1402	11.17	4.11
		1740	11.21	4.07
		2144	11.24	4.09
	12 Feb	0111	10.99	4.29
		0747	10.58	4.70
	8 Mar	1356	11.29	3.99
		1624	11.34	3.94
	12 Apr	0947	11.82	3.46
		1125	11.82	3.46
	7 May	1458	11.22	4.06
		1726	11.28	4.00

TABLE 1
(continued)
GROUND-WATER LEVEL MEASUREMENTS AT PINE KNOLL SHORES

Well I.D.	Measurement Date	Measurement Time	Depth to water from measuring point (ft)	Water level elevation (MSL)
P1A3	14 Jul 84	1219	11.65	3.67
	19 Aug	0727	11.10	4.22
		1139	11.12	4.20
		1457	11.04	4.28
		1938	11.05	4.27
	20 Aug	0009	11.17	4.15
		0436	11.12	4.20
		0905	11.20	4.12
	18 Sep	1046	10.03	5.29
		1237	9.96	5.36
	17 Oct	1353	10.19	5.13
		1510	10.17	5.15
	11 Nov**	1352	10.33	4.99
		1535	10.37	4.95
	12 Dec	0811	11.59	3.73
		0950	11.52	3.80
	18 Jan 85	1439	11.32	4.00
		1623	11.23	4.09
	11 Feb	1003	11.26	4.06
		1403	11.20	4.12
		1742	11.27	4.05
		2146	11.23	4.09
	12 Feb	0112	10.82	4.50
		0749	10.53	4.79
	8 Mar	1357	11.33	3.99
		1623	11.41	3.91
	12 Apr	0947	11.84	3.48
		1125	11.86	3.46
	7 May	1459	11.29	4.03
		1727	11.36	3.96
P1B1	14 Jul 84	1207	8.48	4.69
	19 Aug	0731	7.90	5.27
		1142	7.91	5.26
		1501	7.94	5.23
		1941	7.94	5.23
	20 Aug	0013	8.00	5.17
		0440	7.96	5.21
		0908	7.98	5.19
	18 Sep	1051	5.69	7.48
		1258	8.70	4.47
	17 Oct	1400	7.28	5.89
		1525	7.28	5.89
	11 Nov**	1356	7.93	5.24
		1544	7.93	5.24
	12 Dec	0822	8.57	4.60
		1002	8.58	4.59
	18 Jan 85	1442	8.97	4.20
		1626	8.96	4.21
	11 Feb	1006	7.78	5.39
		1406	7.78	5.39
		1745	7.78	5.39
		2150	7.79	5.38
	12 Feb	0115	7.79	5.38
		0754	7.60	5.57
	8 Mar	1402	8.28	4.89
		1632	8.29	4.88
	12 Apr	1002	8.58	4.59
		1128	8.58	4.59
	7 May	1504	9.11	4.06
		1730	9.11	4.06

TABLE 1
(continued)
GROUND-WATER LEVEL MEASUREMENTS AT PINE KNOLL SHORES

Well I.D.	Measurement Date	Measurement Time	Depth to water from measuring point (ft)	Water level elevation (MSL)
P1C1	14 Jul 84	1140	2.80	4.74
	19 Aug	0737	2.16	5.38
		1148	2.19	5.35
		1505	2.21	5.33
		1944	2.21	5.33
	20 Aug	0016	2.21	5.33
		0444	2.22	5.32
		0910	2.23	5.31
	18 Sep	1056	0.14	7.40
		1305	0.22	7.32
	17 Oct	1405	1.58	5.96
		1529	1.58	5.96
	11 Nov**	1409	2.06	5.48
		1549	2.09	5.45
	12 Dec	0829	2.85	4.69
		1007	2.86	4.68
	18 Jan 85	1446	3.27	4.27
		1628	3.27	4.27
	11 Feb	1007	2.11	5.43
		1409	2.10	5.44
		1748	2.10	5.44
		2151	2.11	5.43
	12 Feb	0118	2.07	5.47
		0756	1.40	6.14
	8 Mar	1405	2.51	5.03
		1637	2.52	5.02
	12 Apr	1010	2.84	4.70
		1132	2.95	4.59
	7 May	1508	4.15	3.39
		1732	3.64	3.90
P1C2	14 Jul 84	1142	2.69	4.74
	19 Aug	0738	2.05	5.38
		1147	2.09	5.34
		1506	2.10	5.33
		1945	2.11	5.32
	20 Aug	0017	2.10	5.33
		0446	2.11	5.32
		0911	2.13	5.30
	18 Sep	1058	0.0	7.43
		1305	0.01	7.42
	17 Oct	1406	1.46	5.97
		1530	1.48	5.95
	11 Nov**	1410	1.96	5.47
		1549	1.96	5.47
	12 Dec	0830	2.74	4.69
		1008	2.75	4.68
	18 Jan 85	1447	3.17	4.26
		1629	3.17	4.26
	11 Feb	1008	2.01	5.42
		1409	1.99	5.44
		1749	2.00	5.43
		2153	1.98	5.45
	12 Feb	0119	1.97	5.46
		0757	1.36	6.07
	8 Mar	1406	2.41	5.02
		1638	2.42	5.01
	12 Apr	1010	2.86	4.57
		1132	2.85	4.58
	7 May	1508	3.53	3.90
		1732	3.53	3.90

TABLE 1
(continued)
GROUND-WATER LEVEL MEASUREMENTS AT PINE KNOLL SHORES

Well I.D.	Measurement Date	Measurement Time	Depth to water from measuring point (ft)	Water level elevation (MSL)
P1C3	14 Jul 84	1143	2.81	4.74
	19 Aug	0739	2.17	5.38
		1146	2.19	5.36
		1507	2.22	5.33
		1946	2.23	5.32
	20 Aug	0019	2.22	5.33
		0447	2.23	5.32
		0912	2.24	5.31
	18 Sep	1100	0.15	7.40
		1305	0.15	7.40
	17 Oct	1406	1.59	5.96
		1530	1.60	5.95
	11 Nov**	1410	2.14	5.41
		1550	2.15	5.40
	12 Dec	0831	2.87	4.68
		1009	2.87	4.68
	18 Jan 85	1447	3.31	4.24
		1629	3.31	4.24
	11 Feb	1009	2.13	5.42
		1410	2.11	5.44
		1751	2.10	5.45
		2155	2.10	5.45
	12 Feb	0120	2.09	5.46
		0757	1.56	5.99
	8 Mar	1407	2.54	5.01
		1638	2.54	5.01
	12 Apr	1010	2.93	4.62
		1132	2.96	4.59
	7 May	1509	3.65	3.90
		1733	3.66	3.89
P1C4	14 Jul 84	1145	3.14	4.41
	19 Aug	0740	2.60	4.95
		1145	2.60	4.95
		1508	2.61	4.94
		1948	2.63	4.92
	20 Aug	0020	2.62	4.93
		0449	2.65	4.90
		0913	2.66	4.89
	18 Sep	1056	0.12	7.43
		1306	0.12	7.43
	17 Oct	1407	1.97	5.58
		1531	1.98	5.57
	11 Nov**	1411	2.59	4.96
		1550	2.54	5.01
	12 Dec	0832	3.11	4.44
		1010	3.13	4.42
	18 Jan 85	1448	3.55	4.00
		1630	3.54	4.01
	11 Feb	1009	2.58	4.97
		1411	2.59	4.96
		1752	2.59	4.96
		2158	2.54	5.01
	12 Feb	0121	2.53	5.02
		0758	2.39	5.16
	8 Mar	1408	2.90	4.65
		1639	2.87	4.68
	12 Apr	1010	3.07	4.48
		1132	3.21	4.34
	7 May	1509	3.84	3.71
		1733	3.83	3.72

TABLE 1
(continued)
GROUND-WATER LEVEL MEASUREMENTS AT PINE KNOLL SHORES

Well I.D.	Measurement Date	Measurement Time	Depth to water from measuring point (ft)	Water level elevation (MSL)
P1D1	14 Jul 84	1200	6.71	4.24
	19 Aug	0745	6.03	4.92
		1151	6.05	4.90
		1511	6.05	4.90
		1950	6.08	4.87
	20 Aug	0024	6.20	4.75
		0455	6.09	4.86
		0917	6.12	4.83
	18 Sep	1100	3.94	7.01
		1315	3.95	7.00
	17 Oct	1414	5.58	5.37
		1552	5.59	5.36
	11 Nov**	1417	6.28	4.67
		1602	6.24	4.71
	12 Dec	0838	6.73	4.22
		1023	6.73	4.22
	18 Jan 85	1450	7.15	3.80
		1632	7.14	3.81
	11 Feb	1012	5.95	5.00
		1414	5.93	5.02
		1754	5.93	5.02
		2158	5.92	5.03
	12 Feb	0123	5.97	4.98
		0802	5.88	5.07
	8 Mar	1412	6.46	4.49
		1651	6.48	4.47
	12 Apr	1016	6.78	4.17
		1137	6.80	4.15
	7 May	1514	7.40	3.55
		1736	7.41	3.54
P1E1	14 Jul 84	1126	6.11	3.22
	19 Aug	0748	5.60	3.73
		1153	5.62	3.71
		1515	5.59	3.74
		1952	5.64	3.69
	20 Aug	0026	5.65	3.68
		0457	5.65	3.68
		0919	5.66	3.67
	18 Sep	1106	4.02	5.31
		1324	4.04	5.29
	17 Oct	1418	5.12	4.21
		1556	5.13	4.20
	11 Nov**	1426	5.53	3.80
		1606	5.52	3.81
	12 Dec	0844	6.04	3.29
		1029	6.03	3.30
	18 Jan 85	1453	6.10	3.23
		1634	6.10	3.23
	11 Feb	1015	5.49	3.84
		1415	5.50	3.83
		1757	5.51	3.82
		2159	5.51	3.82
	12 Feb	0125	5.54	3.79
		0806	4.97	4.36
	8 Mar	1415	5.97	3.36
		1656	6.00	3.33
	12 Apr	1024	6.23	3.10
		1139	6.24	3.09
	7 May	1518	6.34	2.99
		1738	6.35	2.98

TABLE 1
(continued)
GROUND-WATER LEVEL MEASUREMENTS AT PINE KNOLL SHORES

Well I.D.	Measurement Date	Measurement Time	Depth to water from measuring point (ft)	Water level elevation (MSL)
P1E2	14 Jul 84	1128	6.18	3.21
	19 Aug	0750	5.67	3.72
		1154	5.70	3.69
		1516	5.71	3.68
		1954	5.70	3.69
	20 Aug	0027	5.78	3.61
		0459	5.71	3.68
		0920	5.73	3.66
	18 Sep	1106	4.10	5.29
		1325	4.13	5.26
	17 Oct	1418	5.18	4.21
		1557	5.18	4.21
	11 Nov**	1427	5.56	3.83
		1606	5.55	3.84
	12 Dec	0844	6.10	3.29
		1029	6.10	3.29
	18 Jan 85	1454	6.17	3.22
		1635	6.17	3.22
	11 Feb	1017	5.57	3.82
		1416	5.57	3.82
		1758	5.57	3.82
		2200	5.60	3.79
	12 Feb	0126	5.57	3.82
		0807	5.18	4.21
	8 Mar	1416	6.03	3.36
		1656	6.05	3.34
	12 Apr	1024	6.33	3.06
		1139	6.31	3.08
	7 May	1519	6.39	3.00
		1739	6.42	2.97
P1E3	14 Jul 84	1130	6.09	3.20
	19 Aug	0751	5.58	3.71
		1155	5.60	3.69
		1517	5.61	3.68
		1955	5.61	3.68
	20 Aug	0029	5.64	3.65
		0500	5.62	3.67
		0921	5.64	3.65
	18 Sep	1107	4.03	5.26
		1325	4.04	5.25
	17 Oct	1419	5.11	4.18
		1557	5.10	4.19
	11 Nov**	1427	5.48	3.81
		1607	5.50	3.79
	12 Dec	0845	6.02	3.27
		1030	6.02	3.27
	18 Jan 85	1454	6.09	3.10
		1635	6.08	3.21
	11 Feb	1018	5.49	3.80
		1416	5.48	3.81
		1758	5.48	3.81
		2201	5.46	3.83
	12 Feb	0127	5.50	3.79
		0808	5.13	4.16
	8 Mar	1416	5.95	3.34
		1655	5.98	3.31
	12 Apr	1024	6.22	3.07
		1139	6.23	3.06
	7 May	1519	6.31	2.98
		1740	6.33	2.96

TABLE 1
(continued)
GROUND-WATER LEVEL MEASUREMENTS AT PINE KNOLL SHORES

Well I.D.	Measurement Date	Measurement Time	Depth to water from measuring point (ft)	Water level elevation (MSL)
P2A1	14 Jul 84	1403	12.14	2.66
	19 Aug	0801	12.08	2.72
		1126	12.16	2.64
		1546	11.96	2.84
		1926	11.93	2.87
	20 Aug	0101	12.04	2.76
		0424	11.87	2.93
		0927	12.14	2.66
	18 Sep	1036	10.68	4.12
		1157	10.64	4.16
	17 Oct	1427	10.68	4.12
		1607	10.60	4.20
	11 Nov**	1301	11.10	3.70
		1434	11.27	3.53
	12 Dec	0855	12.24	2.56
		1043	12.10	2.70
	18 Jan 85	1502	11.41	3.39
		1641	11.36	3.44
	11 Feb	1027	11.96	2.84
		1422	11.85	2.95
		1808	11.82	2.98
		2205	11.79	3.01
	12 Feb	0132	11.37	3.43
		0812	10.82	3.98
	8 Mar	1427	11.90	2.90
		1708	11.99	2.81
	12 Apr	1037	12.47	2.33
		1145	12.46	2.34
	7 May	1538	11.70	3.10
		1744	11.67	3.13
P2A2	14 Jul 84	1352	12.25	2.67
	19 Aug	0803	12.18	2.74
		1129	12.24	2.68
		1547	12.05	2.87
		1929	12.02	2.90
	20 Aug	0103	12.12	2.80
		0427	12.08	2.84
		0929	12.23	2.69
	18 Sep	1037	10.75	4.17
		1158	10.69	4.23
	17 Oct	1428	10.77	4.15
		1608	10.70	4.22
	11 Nov	1439	11.27	3.65
	12 Dec	0856	12.32	2.60
		1044	12.19	2.73
	18 Jan 85	1503	11.53	3.39
		1642	11.48	3.44
	11 Feb	1028	12.04	2.88
		1422	11.94	2.98
		1809	11.92	3.00
		2206	11.87	3.05
	12 Feb	0133	11.41	3.51
		0813	10.99	3.93
	8 Mar	1429	12.01	2.91
		1707	12.08	2.84
	12 Apr	1037	12.53	2.39
		1145	12.55	2.37
	7 May	1539	11.73	3.19
		1745	11.78	3.14

TABLE 1
(continued)
GROUND-WATER LEVEL MEASUREMENTS AT PINE KNOLL SHORES

Well I.D.	Measurement Date	Measurement Time	Depth to water from measuring point (ft)	Water level elevation (MSL)
P2A3	14 Jul 84	1400	12.48	2.63
	19 Aug	0802	15.11	2.68
		1128	12.45	2.56
		1548	12.21	2.90
		1928	12.23	2.88
	20 Aug	0104	12.32	2.79
		0425	12.28	2.83
		0928	12.48	2.63
	18 Sep	1037	11.00	4.11
		1158	10.88	4.23
	17 Oct	1428	10.93	4.18
		1608	10.91	4.20
	11 Nov**	1304	11.45	3.66
		1435	11.51	3.60
	12 Dec	0857	12.49	2.62
		1045	12.34	2.77
	18 Jan 85	1503	11.73	3.38
		1642	11.63	3.48
	11 Feb	1029	12.27	2.84
		1424	12.17	2.94
		1810	12.18	2.93
		2207	12.07	3.04
	12 Feb	0134	11.47	3.64
		0814	11.14	3.97
	8 Mar	1428	12.30	2.81
		1708	12.29	2.82
	12 Apr	1037	12.77	2.34
		1145	12.77	2.34
	7 May	1540	11.95	3.16
		1746	12.01	3.10
P2B1	14 Jul 84	1304	8.00	3.55
	19 Aug	0753	7.85	3.70
		1123	7.86	3.69
		1523	7.87	3.68
		1922	7.89	3.66
	20 Aug	0035	7.91	3.64
		0355	7.90	3.65
		0932	7.92	3.63
	18 Sep	1023	6.02	5.53
		1150	6.03	5.52
	17 Oct	1433	7.36	4.19
		1616	7.36	4.19
	11 Nov**	1309	7.72	3.83
		1448	7.63	3.92
	12 Dec	0902	8.00	3.55
		1055	7.99	3.56
	18 Jan 85	1506	8.16	3.39
		1646	8.15	3.40
	11 Feb	1030	7.07	4.48
		1427	7.10	4.45
		1812	7.09	4.46
		2211	7.11	4.44
	12 Feb	0139	7.08	4.47
		0818	6.87	4.68
	8 Mar	1432	7.69	3.86
		1717	7.70	3.85
	12 Apr	1048	7.79	3.76
		1148	7.82	3.73
	7 May	1545	8.32	3.23
		1748	8.33	3.22

TABLE 1
(continued)
GROUND-WATER LEVEL MEASUREMENTS AT PINE KNOLL SHORES

Well I.D.	Measurement Date	Measurement Time	Depth to water from measuring point (ft)	Water level elevation (MSL)
P2C1	14 Jul 84	1316	7.34	2.04
	19 Aug	0742	6.36	3.02
		1117	6.42	2.96
		1541	6.39	2.99
		1918	6.42	2.96
	20 Aug	0056	6.44	2.94
		0406	6.44	2.94
		0935	6.46	2.92
	18 Sep	1004	4.57	4.81
		1139	4.58	4.80
	17 Oct	1438	5.78	3.60
	11 Nov**	1315	6.11	3.27
		1456	6.09	3.29
	12 Dec	0912	6.41	2.97
		1103	6.41	2.97
	18 Jan 85	--	--	--
	11 Feb	1035	5.22	4.16
	8 Mar	1436	5.71	3.67
		1722	5.68	3.70
	12 Apr	1052	6.10	3.28
	7 May	1552	6.78	2.60
		1750	6.79	2.59
P2C2	14 Jul 84	1317	5.83	2.60
	19 Aug	0738	5.15	3.28
		1112	5.18	3.25
		1538	5.20	3.23
		1915	5.21	3.22
	20 Aug	0049	5.22	3.21
		0400	5.22	3.21
		0937	5.23	3.20
	18 Sep	1017	3.34	5.09
		1136	3.35	5.08
	17 Oct	1438	4.56	3.87
		1622	4.57	3.86
	11 Nov**	1322	4.90	3.53
		1456	4.88	3.55
	12 Dec	0908	5.20	3.23
		1059	5.20	3.23
	18 Jan 85	1510	5.28	3.15
		1648	5.28	3.15
	11 Feb	1037	4.01	4.42
		1431	4.05	4.38
		1816	4.04	4.39
		2213	4.03	4.40
	12 Feb	0142	4.01	4.42
		0824	3.33	5.10
	8 Mar	1442	4.49	3.94
		1723	4.50	3.93
	12 Apr	1052	4.92	3.51
		1150	4.93	3.50
	7 May	1553	5.59	2.84
		1751	5.59	2.84

TABLE 1
(continued)
GROUND-WATER LEVEL MEASUREMENTS AT PINE KNOLL SHORES

Well I.D.	Measurement Date	Measurement Time	Depth to water from measuring point (ft)	Water level elevation (MSL)
P2C3	14 Jul 84	1312	5.34	2.57
	19 Aug	0739	4.90	3.01
		1113	4.93	2.98
		1539	4.95	2.96
		1916	4.98	2.93
	20 Aug	0050	4.99	2.92
		0402	4.98	2.93
		0938	4.99	2.92
	18 Sep	1018	3.08	4.83
		1137	3.10	4.81
	17 Oct	1439	4.33	3.58
		1623	4.33	3.58
	11 Nov**	1323	4.68	3.23
		1457	4.63	3.28
	12 Dec	0910	4.95	2.96
		1100	4.95	2.96
	18 Jan 85	1510	5.04	2.87
		1648	5.03	2.88
	11 Feb	1039	3.97	3.94
		1432	3.80	4.11
		1817	3.77	4.14
		2215	3.78	4.13
	12 Feb	0143	3.74	4.17
		0825	3.06	4.85
	8 Mar	1443	4.27	3.64
		1724	4.27	3.64
	12 Apr	1052	4.67	3.24
		1150	4.90	3.01
	7 May	1553	5.34	2.57
		1752	5.35	2.56
P2C4	14 Jul 84	1315	5.48	2.33
	19 Aug	0740	5.28	2.53
		1114	5.29	2.52
		1540	5.28	2.53
		1917	5.29	2.52
	20 Aug	0051	5.32	2.49
		0403	5.31	2.50
		0939	5.30	2.51
	18 Sep	1018	4.11	3.70
		1137	4.12	3.69
	17 Oct	1439	4.51	3.30
		1623	4.51	3.30
	11 Nov**	1324	5.04	2.77
		1457	5.04	2.77
	12 Dec	0908	5.23	2.58
		1101	5.24	2.57
	18 Jan 85	1511	5.35	2.46
		1649	5.35	2.46
	11 Feb	1040	4.38	3.43
		1432	4.38	3.43
		1817	4.39	3.42
		2217	4.41	3.40
	12 Feb	0144	4.39	3.42
		0825	4.35	3.46
	8 Mar	1443	4.43	3.38
		1723	4.43	3.38
	12 Apr	1052	4.88	2.93
		1150	4.69	3.12
	7 May	1554	5.18	2.63
		1753	5.19	2.62

TABLE 1
(continued)
GROUND-WATER LEVEL MEASUREMENTS AT PINE KNOLL SHORES

Well I.D.	Measurement Date	Measurement Time	Depth to water from measuring point (ft)	Water level elevation (MSL)
P2D1	14 Jul 84	1323	6.99	1.98
	19 Aug	0734	6.65	2.32
		1109	6.67	2.30
		1534	6.69	2.28
		1911	6.69	2.28
	20 Aug	0045	6.71	2.26
		0410	6.69	2.28
		0941	6.71	2.26
	18 Sep	0959	5.29	3.68
		1133	5.30	3.67
	17 Oct	1453	6.36	2.61
		1630	6.34	2.63
	11 Nov**	1326	6.54	2.43
		1514	6.52	2.45
	12 Dec	0917	6.66	2.31
		1129	6.66	2.31
	18 Jan 85	1513	6.69	2.28
		1651	6.69	2.28
	11 Feb	1048	5.92	3.05
		1435	5.93	3.04
		1820	5.93	3.04
		2219	5.94	3.03
	12 Feb	0146	5.94	3.03
		0826	5.66	3.31
	8 Mar	1445	6.46	2.51
		1737	6.46	2.51
	12 Apr	1106	6.62	2.35
		1155	6.62	2.35
	7 May	1607	6.87	2.10
		1755	6.88	2.09
P2E1	14 Jul 84	1337	5.71	1.45
	19 Aug	0728	5.40	1.76
		1103	5.45	1.71
		1528	5.38	1.78
		1905	5.38	1.78
	20 Aug	0039	5.46	1.70
		0414	5.41	1.75
		0945	5.48	1.68
	18 Sep	0953	4.08	3.08
		1116	4.08	3.08
	17 Oct	1458	4.75	2.41
		1634	4.74	2.42
	11 Nov**	1337	4.37	2.79
		1519	4.38	2.78
	12 Dec	0923	4.67	2.49
		1135	4.62	2.54
	18 Jan 85	1517	4.72	2.44
		1655	4.71	2.45
	11 Feb	1051	4.84	2.32
		1438	4.82	2.34
		1825	4.85	2.31
		2221	4.86	2.30
	12 Feb	0150	4.74	2.42
		0829	4.31	2.85
	8 Mar	1451	4.70	2.46
		1743	4.73	2.43
	12 Apr	1113	4.73	2.43
		1158	4.73	2.43
	7 May	1612	4.34	2.82
		1757	4.39	2.77

TABLE 1
(continued)
GROUND-WATER LEVEL MEASUREMENTS AT PINE KNOLL SHORES

Well I.D.	Measurement Date	Measurement Time	Depth to water from measuring point (ft)	Water level elevation (MSL)
P2E2	14 Jul 84	1334	5.62	1.45
	19 Aug	0729	5.35	1.72
		1104	5.41	1.66
		1529	5.32	1.75
		1906	5.32	1.75
	20 Aug	0040	5.40	1.76
		0416	5.35	1.72
		0946	5.43	1.64
	18 Sep	0953	4.08	2.99
		1117	4.09	2.98
	17 Oct	1458	4.68	2.39
		1634	4.66	2.41
	11 Nov**	1337	4.36	2.71
		1520	4.37	2.70
	12 Dec	0924	4.65	2.42
		1136	4.58	2.49
	18 Jan 85	1518	4.68	2.39
		1655	4.67	2.40
	11 Feb	1052	4.81	2.26
		1438	4.77	2.30
		1826	4.93	2.14
		2222	4.81	2.26
	12 Feb	0151	4.68	2.39
		0830	4.24	2.83
	8 Mar	1450	4.70	2.37
		1742	4.74	2.33
	12 Apr	1113	4.74	2.33
		1158	4.74	2.33
	7 May	1612	4.37	2.70
		1758	4.43	2.64
P2E3	14 Jul 84	1336	5.95	1.21
	19 Aug	0730	5.62	1.54
		1106	5.66	1.50
		1530	5.58	1.58
		1907	5.59	1.57
	20 Aug	0041	5.65	1.42
		0417	5.61	1.55
		0947	5.70	1.46
	18 Sep	0954	4.31	2.85
		1117	4.33	2.83
	17 Oct	1459	4.90	2.26
		1635	4.88	2.28
	11 Nov**	1337	4.49	2.67
		1519	4.52	2.64
	12 Dec	0924	4.82	2.34
		1137	4.75	2.41
	18 Jan 85	1518	4.82	2.34
		1656	4.81	2.35
	11 Feb	1053	5.00	2.16
		1439	4.92	2.24
		1827	4.98	2.18
		2223	4.97	2.19
	12 Feb	0152	4.84	2.32
		0830	4.39	2.77
	8 Mar	1451	4.83	2.33
		1743	4.85	2.31
	12 Apr	1113	4.85	2.31
		1158	4.85	2.31
	7 May	1613	4.48	2.68
		1758	4.53	2.63

**These measurements were made using an electric water-level indicator.

WATER-LEVEL DATA

FOR

SURF CITY

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TABLE 1

ATLANTIC OCEAN TIDAL MEASUREMENTS AT SURF CITY

Measurement Date	Measurement Time	Depth to water from measuring point (ft)	Water level elevation (MSL)
21 Aug 84	0645	22.23	-0.23
	1045	22.00	0.00
	1527	20.34	1.66
	1850	21.20	0.80
	2253	22.55	-0.55
22 Aug	0326	20.30	1.70
	0716	22.30	-0.30
10 Nov	1409	22.49	-0.49
	1711	20.99	1.01
13 Dec	0729	20.59	1.41
21 Jan 85	1420	21.29	0.71
12 Feb	1315		1.4[a]
	1750		-0.7[a]
	2225		-0.1[a]
13 Feb	0145		1.9[a]
	0702		-0.4[a]
	1020		-1.0[a]
8 Mar	0814	17.29	4.71
	1028	19.77	2.23
13 Apr	1118		-0.3[a]
8 May	0901		1.4[a]

[a] Estimated from tidal tables (NOAA, 1985).

TABLE 2

INTRACOASTAL WATERWAY WATER-LEVEL MEASUREMENTS AT SURF CITY

Measurement Date	Measurement Time	Staff gauge reading (ft)	Water level elevation (MSL)
21 Aug 84	0708	1.62	1.12
	1106	0.95	0.45
	1518	1.38	0.88
	1917	2.05	1.55
	2245	1.54	1.04
22 Aug	0351	1.37	0.87
	0709	1.68	1.18
18 Sep	1614	2.26	1.76
	1845	2.28	1.78
16 Oct	0752	2.24	1.74
	1130	2.30	1.80
10 Nov	1358	2.09	1.59
	1726	1.47	0.97
13 Dec	0735	0.72	0.22
	0852	0.72	0.22
21 Jan 85	1640	0.50	0.00
12 Feb	1310	1.99	1.49
	1745	1.56	1.06
	2218	0.70	0.20
13 Feb	0138	0.91	0.41
	0658	1.53	1.03
	1015	0.85	0.35
8 Mar	0802	1.59	1.09
	1034	2.20	1.70
13 Apr	1021	0.21	-0.29
	1215	-0.01	-0.51
8 May	0805	1.10	0.60
	0958	1.00	0.50

TABLE 3

GROUND-WATER LEVEL MEASUREMENTS AT SURF CITY

Well I.D.	Measurement Date	Measurement Time	Depth to water from measuring point (ft)	Water level elevation (MSL)
S1A1	21 Aug 84	0659	7.82	1.51
		1054	8.02	1.31
		1544	7.47	1.86
		1858	7.41	1.92
		2311	7.85	1.48
	22 Aug	0335	7.66	1.67
		0732	7.80	1.53
	18 Sep	1554	6.72	2.61
		1719	6.88	2.45
	16 Oct	0738	6.46	2.87
		1024	6.28	3.05
	10 Nov	1438	7.10	2.23
		1601	7.28	2.05
	13 Dec	0712	8.01	1.32
		0840	7.82	1.51
	21 Jan 85	1022	7.78	1.55
		1142	7.92	1.41
	12 Feb	1300	6.65	2.68
		1737	6.98	2.35
		2202	7.53	1.80
	13 Feb	0121	7.10	2.23
		0640	7.11	2.22
		0950	7.57	1.76
	8 Mar	0833	7.10	2.23
		0923	6.99	2.34
	13 Apr	1108	8.32	1.01
		1158	8.30	1.03
	8 May	0847	7.79	1.54
		0945	7.69	1.64
S1A2	21 Aug 84	0700	7.79	1.29
		1055	8.03	1.05
		1545	7.42	1.66
		1859	7.38	1.70
		2313	7.80	1.28
	22 Aug	0336	7.61	1.47
		0731	7.76	1.32
	18 Sep	1554	6.75	2.33
		1718	6.91	2.17
	16 Oct	0739	6.50	2.58
		1025	6.28	2.80
	10 Nov	1439	7.00	2.08
		1604	7.30	1.78
	13 Dec	0713	7.96	1.12
		0841	7.77	1.31
	21 Jan 85	1024	7.72	1.36
		1143	7.89	1.19
	12 Feb	1301	6.75	2.33
		1738	7.00	2.08
		2203	7.55	1.53
	13 Feb	0122	7.09	1.99
		0641	7.13	1.95
		0951	7.58	1.50
	8 Mar	0832	7.07	2.01
		0923	6.98	2.10
	13 Apr	1108	8.34	0.74
		1158	8.26	0.82
	8 May	0848	7.76	1.32
		0945	7.65	1.43

TABLE 3
(continued)
GROUND-WATER LEVEL MEASUREMENTS AT SURF CITY

Well I.D.	Measurement Date	Measurement Time	Depth to water from measuring point (ft)	Water level elevation (MSL)
S1A3	21 Aug 84	0702	8.41	1.03
		1056	8.65	0.79
		1546	7.82	1.62
		1900	7.99	1.45
		2308	8.49	0.95
	22 Aug	0338	8.11	1.33
		0730	8.35	1.09
	18 Sep	1553	7.33	2.11
		1717	7.55	1.89
	16 Oct	0739	7.30	2.14
		1025	6.89	2.55
	10 Nov	1440	8.03	1.41
		1607	8.10	1.34
	13 Dec	0715	8.57	0.87
		0842	8.23	1.21
	21 Jan 85	1025	8.22	1.22
		1144	8.47	0.97
	12 Feb	1302	7.63	1.81
		1739	8.04	1.40
		2204	8.42	1.02
	13 Feb	0123	7.70	1.74
		0642	8.11	1.33
		0952	8.48	0.96
	8 Mar	0831	7.61	1.83
		0924	7.61	1.83
	13 Apr	1108	9.02	0.42
		1158	8.89	0.55
	8 May	0849	8.35	1.09
		0946	8.18	1.26
S1B1	21 Aug 84	0653	4.20	1.38
		1058	4.21	1.37
		1534	4.25	1.33
		1908	4.15	1.43
		2301	4.02	1.56
	22 Aug	0342	4.13	1.45
		0721	4.11	1.47
	18 Sep	1546	3.54	2.04
		1703	3.51	2.07
	16 Oct	0732	2.69	2.89
		0930	2.75	2.83
	10 Nov	1427	3.42	2.16
		1540	3.43	2.15
	13 Dec	0703	3.96	1.62
		0827	3.99	1.59
	21 Jan 85	1017	4.13	1.45
		1232	4.12	1.46
	12 Feb	1254	3.43	2.15
		1740	3.37	2.21
		2206	3.40	2.18
	13 Feb	0125	3.48	2.10
		0648	3.45	2.13
		0959	3.49	2.09
	8 Mar	0826	3.91	1.67
		0908	3.90	1.68
	13 Apr	1118	4.38	1.20
		1203	4.39	1.19
	8 May	0855	3.84	1.74
		0949	3.85	1.73

TABLE 3
(continued)
GROUND-WATER LEVEL MEASUREMENTS AT SURF CITY

Well I.D.	Measurement Date	Measurement Time	Depth to water from measuring point (ft)	Water level elevation (MSL)
S1B2	21 Aug 84	0654	4.11	1.26
		1059	4.11	1.26
		1535	4.14	1.23
		1909	4.08	1.29
		2303	4.03	1.34
	22 Aug	0344	4.04	1.33
		0722	4.01	1.36
	18 Sep	1547	3.40	1.97
		1703	3.38	1.99
	16 Oct	0733	2.60	2.77
		0930	2.65	2.72
	10 Nov	1430	3.33	2.04
		1545	3.33	2.04
	13 Dec	0704	3.85	1.52
		0828	3.86	1.51
	21 Jan 85	1018	4.00	1.37
		1233	4.00	1.37
	12 Feb	1255	3.30	2.07
		1741	3.23	2.14
		2207	3.28	2.09
	13 Feb	0126	3.34	2.03
		0649	3.31	2.06
		0959	3.35	2.02
	8 Mar	0826	3.72	1.65
		0908	3.72	1.65
	13 Apr	1118	4.50	0.87
		1203	4.51	0.86
	8 May	0856	3.70	1.67
		0949	3.71	1.66
S1B3	21 Aug 84	0655	4.36	0.90
		1100	4.40	0.86
		1536	4.32	0.94
		1911	4.25	1.01
		2304	4.31	0.95
	22 Aug	0345	4.27	0.99
		0723	4.27	0.99
	18 Sep	1547	3.64	1.62
		1704	3.63	1.63
	16 Oct	0733	3.06	2.20
		0931	3.12	2.14
	10 Nov	1431	3.72	1.54
		1553	3.76	1.50
	13 Dec	0705	4.28	0.98
		0829	4.25	1.01
	21 Jan 85	1018	4.29	0.97
		1233	4.36	0.90
	12 Feb	1255	3.66	1.60
		1741	3.70	1.56
		2208	3.90	1.36
	13 Feb	0127	3.80	1.46
		0649	3.81	1.45
		1000	3.97	1.29
	8 Mar	0827	4.07	1.19
		0908	4.03	1.23
	13 Apr	1118	4.72	0.54
		1203	4.70	0.56
	8 May	0857	4.15	1.11
		0950	4.13	1.13

TABLE 3
(continued)
GROUND-WATER LEVEL MEASUREMENTS
AT SURF CITY

Well I.D.	Measurement Date	Measurement Time	Depth to water from measuring point (ft)	Water level elevation (MSL)
S3A1	21 Aug 84	0641	10.68	1.58
		1042	11.01	1.25
		1458	10.31	1.95
		1850	10.34	1.92
		2254	10.77	1.49
	22 Aug	0302	10.53	1.73
		0639	10.58	1.68
	18 Sep	1619	8.89	3.37
		1817	9.14	3.12
	16 Oct	0820	9.30	2.96
		1459	8.68	3.58
	10 Nov	1518	10.35	1.91
		1655	10.33	1.93
	13 Dec	0742	10.79	1.47
		0856	10.54	1.72
	21 Jan 85	1051	10.72	1.54
		1427	11.08	1.18
	12 Feb	1223	9.50	2.76
		1722	9.87	2.39
		2221	10.26	2.00
	13 Feb	0140	9.73	2.53
		0615	10.12	2.14
		0928	10.43	1.83
	8 Mar	0901	9.82	2.44
		1014	10.02	2.24
	13 Apr	1035	11.11	1.15
		1135	11.05	1.21
	8 May	0810	10.62	1.64
		0923	10.46	1.80
S3A2	21 Aug 84	0642	10.46	1.58
		1043	10.80	1.24
		1501	10.07	1.97
		1851	10.11	1.93
		2255	10.99	1.05
	22 Aug	0303	10.57	1.47
		0641	10.36	1.68
	18 Sep	1620	8.69	3.35
		1819	8.94	3.10
	16 Oct	0822	9.15	2.89
		1500	8.51	3.53
	10 Nov	1520	10.20	1.84
		1656	10.15	1.89
	13 Dec	0743	10.60	1.44
		0857	10.35	1.69
	21 Jan 85	1054	10.55	1.49
		1427	10.93	1.11
	12 Feb	1223	9.32	2.72
		1723	9.70	2.34
		2224	10.06	1.98
	13 Feb	0141	9.56	2.48
		0616	9.96	2.08
		0929	10.28	1.76
	8 Mar	0859	9.73	2.31
		1014	9.82	2.22
	13 Apr	1035	10.98	1.06
		1135	10.91	1.13
	8 May	0812	10.44	1.60
		0924	10.28	1.76

TABLE 3
(continued)
GROUND-WATER LEVEL MEASUREMENTS AT SURF CITY

Well I.D.	Measurement Date	Measurement Time	Depth to water from measuring point (ft)	Water level elevation (MSL)
S3A3	21 Aug 84	0643	10.82	1.10
		1044	11.19	0.73
		1459	10.26	1.66
		1853	10.41	1.51
		2256	10.56	1.36
	22 Aug	0304	10.31	1.61
		0642	10.69	1.23
	18 Sep	1620	9.23	2.69
		1818	9.57	2.35
	16 Oct	0821	9.69	2.23
		1500	8.98	2.94
	10 Nov	1517	10.70	1.22
		1654	10.59	1.33
	13 Dec	0744	10.79	1.13
		0857	10.58	1.34
	21 Jan 85	1055	10.76	1.16
		1428	11.47	0.15
	12 Feb	1224	9.84	2.08
		1724	10.33	1.59
		2226	10.69	1.23
	13 Feb	0142	9.95	1.97
		0616	10.51	1.41
		0929	10.93	0.99
	8 Mar	0902	9.99	1.93
		1015	10.17	1.75
	13 Apr	1035	11.45	0.47
		1135	11.32	0.60
	8 May	0811	10.86	1.06
		0925	10.62	1.30
S3B1	21 Aug 84	0715	8.32	1.63
		1055	8.50	1.45
		1444	8.31	1.64
		1900	8.20	1.75
		2247	8.26	1.69
	22 Aug	0251	8.30	1.65
		0653	8.25	1.70
	18 Sep	1626	6.53	3.42
		1751	6.55	3.40
	16 Oct	0802	6.99	2.96
	10 Nov	1455	7.78	2.17
		1636	7.84	2.11
	13 Dec	0755	8.31	1.64
		0930	8.27	1.68
	21 Jan 85	--	--	--
	12 Feb	1229	7.29	2.66
	8 Mar	0850	8.00	1.95
		0951	7.98	1.97
	13 Apr	1045	8.56	1.39
	8 May	0821	8.22	1.73
		0928	8.18	1.77

TABLE 3
(continued)
GROUND-WATER LEVEL MEASUREMENTS AT SURF CITY

Well I.D.	Measurement Date	Measurement Time	Depth to water from measuring point (ft)	Water level elevation (MSL)
S3B2	21 Aug 84	0651	6.24	1.55
		1050	6.40	1.39
		1449	6.23	1.56
		1856	6.12	1.67
		2240	6.22	1.57
	22 Aug	0253	6.21	1.58
		0648	6.17	1.62
	18 Sep	1639	4.58	3.21
		1753	4.61	3.18
	16 Oct	0803	4.86	2.93
		1357	4.62	3.17
	10 Nov	1507	5.68	2.11
		1629	5.72	2.07
	13 Dec	0757	6.26	1.53
		0905	6.20	1.59
	21 Jan 85	1040	6.21	1.58
		1507	6.38	1.41
	12 Feb	1230	5.25	2.54
		1726	5.35	2.44
		2228	5.59	2.20
	13 Feb	0144	5.45	2.34
		0621	5.50	2.29
		0936	5.65	2.14
	8 Mar	0855	5.87	1.92
		0953	5.83	1.96
	13 Apr	1053	6.50	1.29
		1141	6.50	1.29
	8 May	0833	6.09	1.70
		0929	6.07	1.72
S3B3	21 Aug 84	0652	6.55	1.27
		1051	6.81	1.01
		1445	6.49	1.33
		1857	6.33	1.49
		2241	6.58	1.24
	22 Aug	0255	6.54	1.28
		0649	6.47	1.35
	18 Sep	1640	4.66	3.16
		1753	4.72	3.10
	16 Oct	0804	5.15	2.67
		1358	4.71	3.11
	10 Nov	1508	6.11	1.71
		1631	6.18	1.64
	13 Dec	0758	6.52	1.30
		0906	6.41	1.41
	21 Jan 85	1042	6.34	1.48
		1507	6.74	1.08
	12 Feb	1231	5.25	2.57
		1727	5.90	1.92
		2229	6.22	1.60
	13 Feb	0145	5.98	1.84
		0621	6.09	1.73
		0936	6.35	1.47
	8 Mar	0856	6.17	1.65
		0953	6.14	1.68
	13 Apr	1053	7.06	0.76
		1141	7.03	0.79
	8 May	0824	6.55	1.27
		0930	6.49	1.33

TABLE 3
(continued)
GROUND-WATER LEVEL MEASUREMENTS AT SURF CITY

Well I.D.	Measurement Date	Measurement Time	Depth to water from measuring point (ft)	Water level elevation (MSL)
S3B4	21 Aug 84	0654	6.96	1.19
		1052	7.17	0.98
		1447	6.54	1.61
		1858	6.62	1.53
		2243	7.02	1.13
	22 Aug	0256	6.76	1.39
		0650	6.84	1.31
	18 Sep	1641	5.18	2.97
		1754	5.30	2.84
	16 Oct	0805	6.70	1.45
		1359	6.02	2.13
	10 Nov	1511	7.45	0.70
		1633	7.38	0.77
	13 Dec	0800	7.62	0.53
		0907	7.39	0.76
	21 Jan 85	1043	7.54	0.61
		1508	8.21	-0.06
	12 Feb	1231	6.93	1.22
		1728	7.40	0.75
		2230	7.58	0.57
	13 Feb	0146	7.00	1.15
		0622	7.48	0.67
		0937	7.79	0.36
	8 Mar	0857	7.06	1.09
		0953	7.15	1.00
	13 Apr	1053	8.31	-0.16
		1141	8.19	-0.04
	8 May	0825	7.67	0.48
		0931	7.51	0.64
S3B5	21 Aug 84	0655	6.77	1.55
		1053	6.93	1.39
		1448	6.77	1.55
		1859	6.66	1.66
		2244	6.76	1.56
	22 Aug	0257	6.75	1.57
		0651	6.71	1.61
	18 Sep	1641	5.11	3.21
		1754	5.14	3.18
	16 Oct	0806	5.39	2.93
		1359	5.16	3.16
	10 Nov	1512	6.21	2.11
		1634	6.25	2.07
	13 Dec	0801	6.78	1.54
		0908	6.72	1.60
	21 Jan 85	1039	6.71	1.61
		1508	6.90	1.42
	12 Feb	1232	5.75	2.57
		1728	5.87	2.45
		2231	6.07	2.25
	13 Feb	0147	5.96	2.36
		0622	6.01	2.31
		0938	6.17	2.15
	8 Mar	0854	6.18	2.14
		0952	6.36	1.96
	13 Apr	1053	7.01	1.31
		1141	7.00	1.32
	8 May	0832	6.60	1.72
		0932	6.58	1.74

TABLE 3
(continued)
GROUND-WATER LEVEL MEASUREMENTS AT SURF CITY

Well I.D.	Measurement Date	Measurement Time	Depth to water from measuring point (ft)	Water level elevation (MSL)
S3C1	21 Aug 84	0701	3.48	1.35
		1100	3.10	1.73
		1507	3.63	1.20
		1904	3.46	1.37
		2310	3.45	1.38
	22 Aug	0311	3.51	1.32
		0702	3.44	1.39
	18 Sep	1610	2.67	2.16
		1736	2.59	2.24
	16 Oct	0748	2.61	2.22
		1133	2.69	2.14
	10 Nov	1448	3.00	1.83
		1616	3.07	1.76
	13 Dec	0819	3.44	1.39
		0920	3.43	1.40
	21 Jan 85	1030	3.41	1.42
		1610	3.52	1.31
	12 Feb	1245	2.72	2.11
		1730	2.87	1.96
		2213	2.98	1.85
	13 Feb	0131	3.01	1.82
		0631	2.98	1.85
		0942	3.06	1.77
	8 Mar	0841	3.31	1.52
		0940	3.29	1.54
	13 Apr	1100	3.73	1.10
		1148	3.75	1.08
	8 May	0838	3.29	1.54
		0938	3.32	1.51
S3C2	21 Aug 84	0702	3.96	1.34
		1101	4.08	1.22
		1508	4.10	1.20
		1906	3.94	1.36
		2311	3.94	1.36
	22 Aug	0314	3.99	1.31
		0703	3.91	1.39
	18 Sep	1610	3.12	2.18
		1736	3.04	2.26
	16 Oct	0749	3.16	2.14
		1133	3.23	2.07
	10 Nov	1449	3.55	1.75
		1617	3.63	1.67
	13 Dec	0820	3.99	1.31
		0921	3.98	1.32
	21 Jan 85	1031	3.96	1.34
		1610	4.05	1.25
	12 Feb	1246	3.26	2.04
		1731	3.39	1.91
		2214	3.52	1.78
	13 Feb	0133	3.57	1.73
		0632	3.49	1.81
		0942	3.58	1.72
	8 Mar	0840	3.83	1.47
		0939	3.80	1.50
	13 Apr	1100	4.27	1.03
		1148	4.29	1.01
	8 May	0839	3.85	1.45
		0938	3.87	1.43

TABLE 3
(continued)
GROUND-WATER LEVEL MEASUREMENTS AT SURF CITY

Well I.D.	Measurement Date	Measurement Time	Depth to water from measuring point (ft)	Water level elevation (MSL)
S3C3	21 Aug 84	0703	4.80	0.79
		1102	4.94	0.65
		1509	4.89	0.70
		1907	4.71	0.88
		2312	4.76	0.83
	22 Aug	0313	4.82	0.77
		0705	4.75	0.84
	18 Sep	1611	3.84	1.75
		1736	3.78	1.81
	16 Oct	0749	3.75	1.84
		1134	3.79	1.80
	10 Nov	1450	4.24	1.35
		1618	4.30	1.29
	13 Dec	0822	4.76	0.83
		0921	4.73	0.86
	21 Jan 85	1032	4.69	0.90
		1611	4.87	0.72
	12 Feb	1247	4.08	1.51
		1732	4.26	1.33
		2215	4.49	1.10
	13 Feb	0134	4.48	1.11
		0632	4.39	1.20
		0943	4.54	1.05
	8 Mar	0839	4.70	0.89
		0939	4.66	0.93
	13 Apr	1100	5.21	0.38
		1148	5.29	0.30
	8 May	0840	4.77	0.82
		0939	4.78	0.81

APPENDIX F

METHOD FOR COMPUTATION OF POROSITY

The effective porosity of the shallow aquifer in each study area was computed by correlating precipitation with changes in water levels observed in the observation well that was equipped with a continuous stage recorder (Figures 1, 2 and 3). Well K3D1 in Kill Devil Hills, well P2C1 in Pine Knoll Shores and well S3B1 in Surf City were equipped with recorders for observing water-level changes.

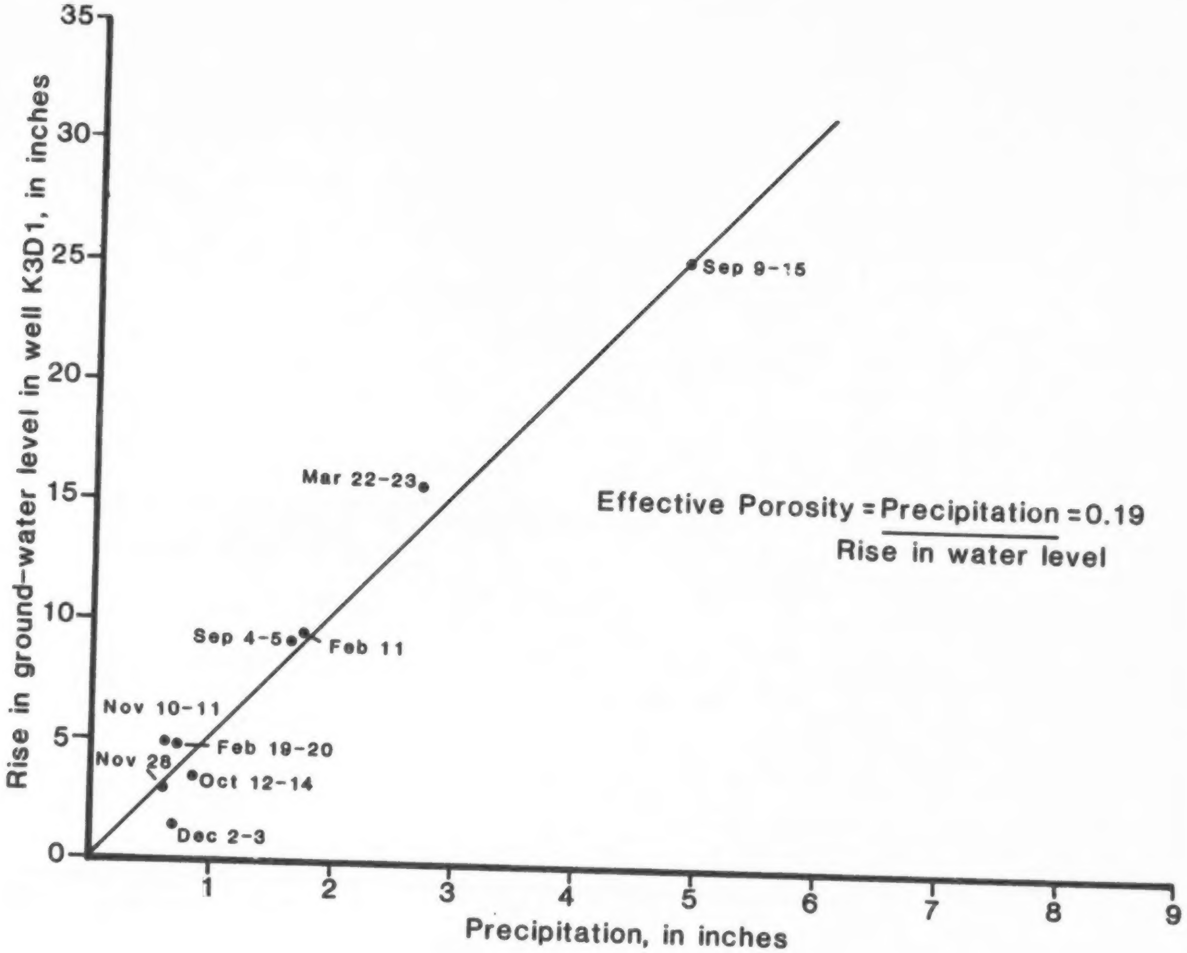

Figure 1. Relation between precipitation and ground-water levels at Kill Devil Hills.

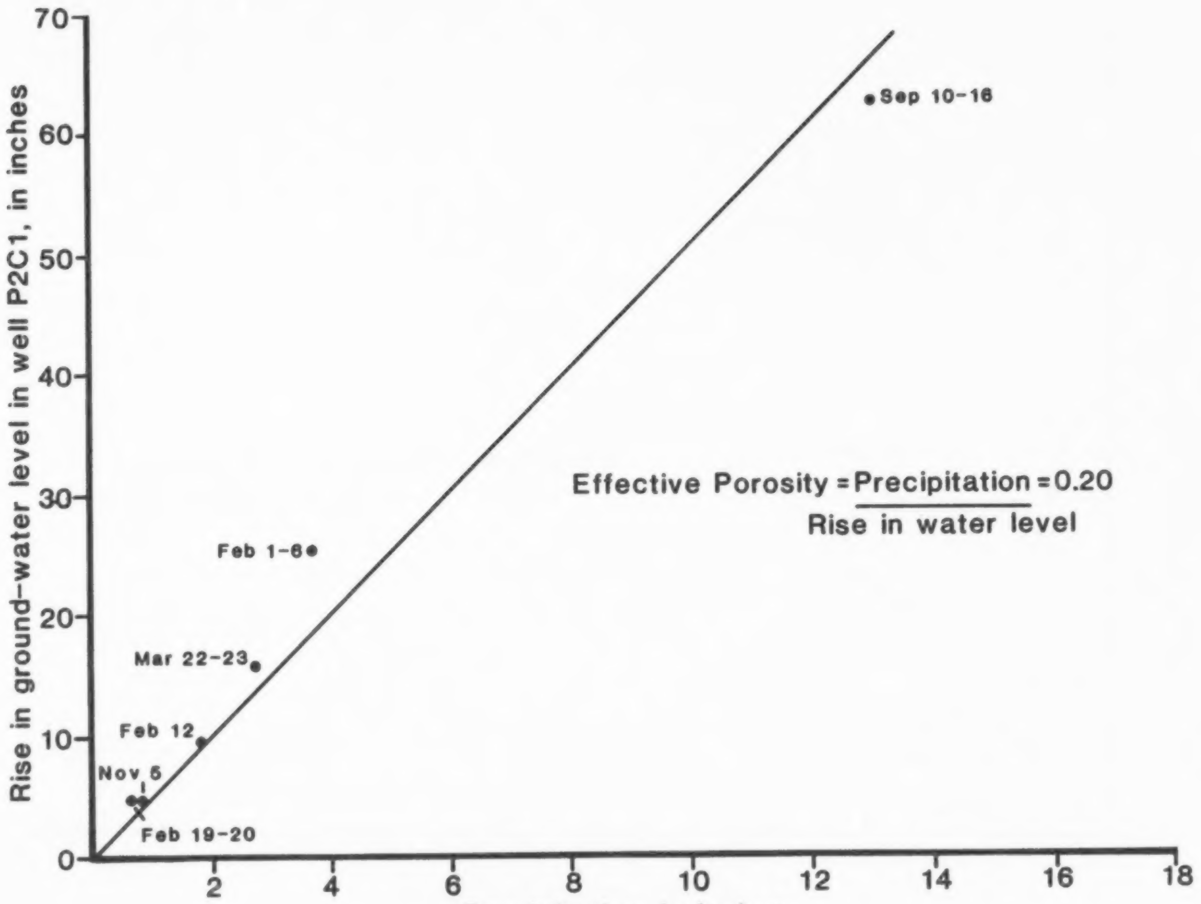

Figure 2. Relation between precipitation and ground-water levels at Pine Knoll Shores.

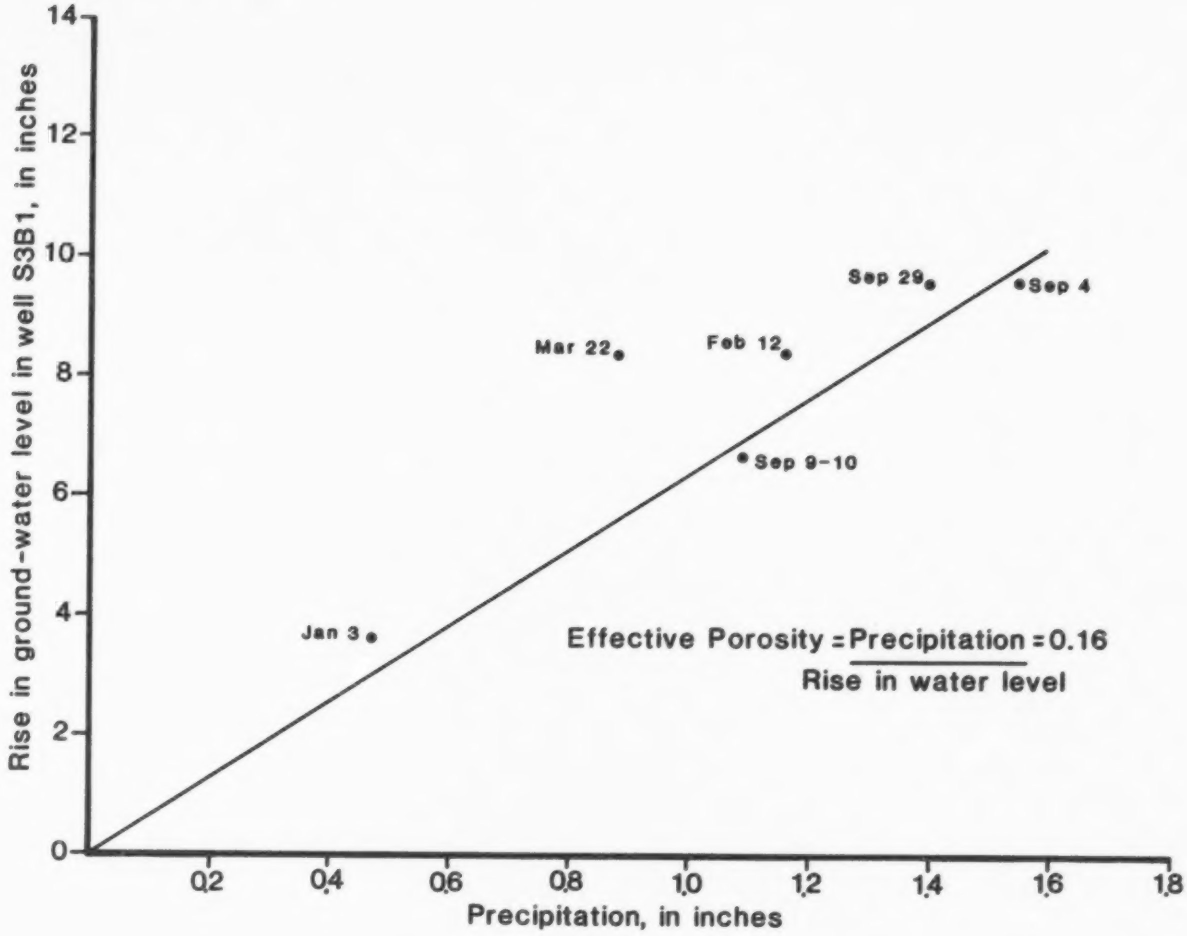

Figure 3. Relation between precipitation and ground-water levels at Surf City.

APPENDIX G

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METHOD FOR COMPUTATION OF PERCOLATION

Monthly percolation to the shallow aquifer was computed in general conformance with procedures outlined by the EPA (Fenn, et al., 1975). The computations were tabulated as shown below and the computation for each parameter proceeded as follows:

Water Balance Computations

	Month												
Parameter	J	F	M	A	M	J	J	A	S	O	N	D	Annual
(1) E_{tp}													
(2) P													
(3) I													
(4) $I-E_{tp}$													
(5) Σ Neg $(I-E_{tp})$													
(6) S													
(7) ΔS													
(8) E_{ta}													
(9) PERC													

(1) E_{tp} is potential evaportranspiration. Monthly estimates of E_{tp} were made using the Thornthwaite Method. The equation for monthly E_{tp} is:

$$E_{tp} = 1.6 \left(\frac{10t}{E}\right)^{a} \quad \text{(cm)}$$

where: $a = (.675 \times 10^{-6})\,E^3 - (.771 \times 10^{-4})\,E^2 + .01792E + .49239;$

t = mean monthly temperature, in °C; and

$$E = \sum_{i-1}^{i=12} \left(\frac{ti}{5}\right)^{1.514}$$ is the temperature efficiency index.

The temperature efficiency index was computed with the aid of Figure 1. Figure 2 was used to aid in computing E_{tp}.

The monthly values of E_{tp} were corrected for sunlight and days of the month using Table 1.

The monthly E_{tp} values were then converted from centimeters to inches.

(2) P is mean monthly precipitation determined from National Weather Service records or from local observations.

(3) I is mean monthly infiltration. Mean monthly infiltration was assumed to be equal to precipitation.

(4) $(I-E_{tp})$ was used to determine periods of moisture excess in the soil. A negative value of $(I-E_{tp})$ indicates the amount by which the infiltration fails to supply the potential water need of the vegetated area. A positive value indicates the amount of excess water which is available for soil moisture recharge and percolation.

(5) Σ Neg $(I-E_{tp})$ is the accumulated potential water loss. The accumulated potential water loss with which to start the computations is zero. This value is assigned to the last month having a positive value of $(I-E_{tp})$. This is reasonable because the soil moisture at the end of the wet season is at field capacity.

(6) S is soil moisture storage. This parameter represents the moisture retained in the soil after a given amount of accumulated potential water loss or gain has occurred.

The value of soil moisture storage when accumulated potential water loss is zero was calculated by multiplying available water capacity of the soil by thickness of the soil cover. The thickness of the soil cover was estimated to be 0.5 feet based on the results of the boring program. The available water capacity of the soil was estimated to be 0.133 using Table 2 and the texture class of the soils as estimated from field observations during the drilling program.

(7) ΔS is the monthly change in soil moisture and was computed using the monthly soil moisture data determined in (6) above.

(8) E_{ta} is the actual monthly evapotranspiration. When $(I-E_{tp})$ is positive, the rate of evapotranspiration is equivalent to E_{tp}. When $(I-E_{tp})$ is negative, evapotranspiration is limited to $E_{ta} = E_{tp} + [(I-E_{tp})-\Delta S]$.

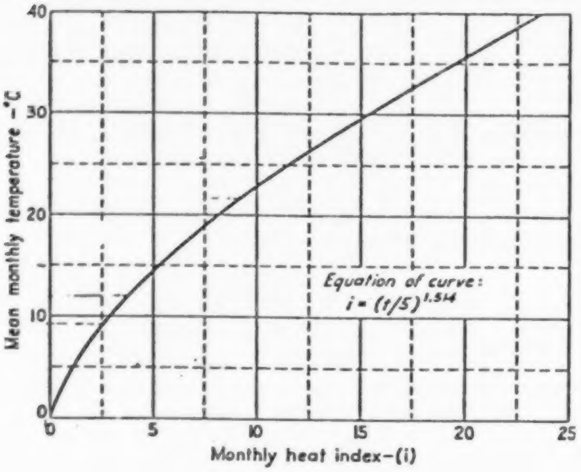

Figure 1. Relation between monthly heat index and temperature (Israelsen and Hansen, 1962)

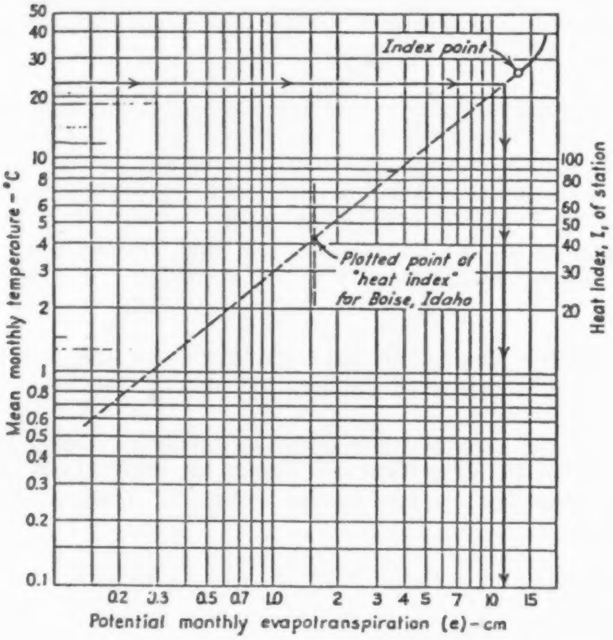

Figure 2. Nanograph for computing monthly evapotranspiration (Israelsen and Hansen, 1962)

TABLE 1

RELATION OF CORRECTION FACTOR TO MONTH AND LATITUDE
(IRAELSEN AND HANSEN, 1962)

N. Lat.	J	F	M	A	M	J	J	A	S	O	N	D
0	1.04	0.94	1.04	1.01	1.04	1.01	1.04	1.04	1.01	1.04	1.01	1.04
10	1.00	0.91	1.03	1.03	1.08	1.06	1.08	1.07	1.02	1.02	0.98	0.99
20	0.95	0.90	1.03	1.05	1.13	1.11	1.14	1.11	1.02	1.00	0.93	0.94
30	0.90	0.87	1.03	1.08	1.18	1.17	1.20	1.14	1.03	0.98	0.89	0.88
35	0.87	0.85	1.03	1.09	1.21	1.21	1.23	1.16	1.03	0.97	0.86	0.85
40	0.84	0.83	1.03	1.11	1.24	1.25	1.27	1.18	1.04	0.96	0.83	0.81
45	0.80	0.81	1.02	1.13	1.28	1.29	1.31	1.21	1.04	0.94	0.79	0.75
50	0.74	0.78	1.02	1.15	1.33	1.36	1.37	1.25	1.06	0.92	0.76	0.70

TABLE 2

RELATION BETWEEN SELECTED SOIL CHARACTERISTICS (PERRIER AND GIBSON, 1980)

	Texture class		MIR	Porosity	Ksat	AWC	Evap
	USDA	USCS	in./hr	vol/vol	in./hr	vol/vol	coef.
1	CoS	GW	0.50	0.351	11.950	0.067	3.3
2	CoSL	GP	0.45	0.376	7.090	0.087	3.3
3	S	SW	0.40	0.389	6.620	0.133	3.3
4	FS	SM	0.39	0.371	5.400	0.122	3.3
5	LS	SM	0.38	0.330	2.780	0.101	3.4
6	LFS	SM	0.34	0.401	1.000	0.540	3.3
7	LVFS	SM	0.32	0.390	0.910	0.086	3.4
8	SL	SM	0.30	0.442	0.670	0.123	3.8
9	FSL	SM	0.25	0.458	0.550	0.131	4.5
10	VFSL	MH	0.25	0.511	0.330	0.117	5.0
11	L	ML	0.20	0.521	0.210	0.156	4.5
12	SIL	ML	0.17	0.535	0.110	0.199	5.0
13	SCL	SC	0.11	0.453	0.084	0.119	4.7
14	CL	CL	0.09	0.582	0.065	0.127	3.9
15	SICL	CL	0.07	0.588	0.041	0.149	4.2
16	SC	CH	0.06	0.572	0.065	0.078	3.6
17	SIC	CH	0.02	0.592	0.033	0.123	3.8
18	C	CH	0.01	0.680	0.022	0.115	3.5
Solid waste				0.526	0.030	0.156	4.5

*USDA = USDA Soil Classification System, Co = coarse, C = clay, SI = silt, S = sand, L = loam, F = fine, V = very;
USCS = Unified Soil Classification System, S = sand, M = silt, L = low liquid limit, H = high liquid limit, W = well graded;
MIR = Minimum Infiltration Rate;
Ksat = Hydraulic Conductivity; and
AWC = Available Water Capacity.

(9) PERC is the monthly percolation rate. Monthly percolation was determined as:

$$PERC = I - E_{ta} - \Delta S$$

Percolation computations for each of the study areas are summarized in Tables 3, 4 and 5.

TABLE 3

SUMMARY OF PERCOLATION COMPUTATIONS FOR KILL DEVIL HILLS

Parameter	1984								1985				
	May	June	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May
E_{tp}	3.88	5.41	5.82	5.87	3.87	3.09	1.19	1.06	0.12	0.27	1.22	2.57	4.08
P	5.87	0.88	7.35	3.39	7.01	1.07	2.49	1.38	5.00	3.85	2.60	1.09	3.27
I	5.87	0.88	7.35	3.39	7.01	1.07	2.49	1.38	5.00	3.85	2.60	1.09	3.27
$I-E_{tp}$	1.99	-4.53	1.53	-2.48	3.14	-2.02	1.30	0.32	4.88	3.58	1.38	-1.48	-0.81
ΣNeg $(I-E_{tp})$		-4.53		-2.48		-2.02						-1.48	-2.29
S	0.80	0.00	0.80	0.00	0.80	0.00	0.80	0.80	0.80	0.80	0.80	0.00	0.00
ΔS	0.00	-0.80	0.80	-0.80	0.80	-0.80	0.80	0.00	0.00	0.00	0.00	-0.80	0.00
E_{ta}	3.88	1.68	5.82	4.19	3.87	1.87	1.19	1.06	0.12	0.27	1.22	1.89	3.27
PERC	1.99	0.00	0.73	0.00	2.34	0.00	0.50	0.32	4.88	3.58	1.38	0.00	0.00

TABLE 4

SUMMARY OF PERCOLATION COMPUTATIONS FOR ATLANTIC BEACH/PINE KNOLL SHORES

Parameter	1984								1985				
	May	June	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May
E_{tp}	4.08	5.71	6.25	6.19	3.92	3.39	1.27	1.21	0.20	0.52	1.37	2.69	5.33
P	10.34	6.94	8.54	1.42	13.98	0.51	2.58	2.15	2.54	6.43	3.93	0.71	7.38
I	10.34	6.94	8.54	1.42	13.98	0.51	2.58	2.15	2.54	6.43	3.93	0.71	7.38
$I-E_{tp}$	6.26	1.23	2.29	-4.77	10.06	-2.88	1.31	0.94	2.34	5.91	2.56	-1.98	2.05
$\Sigma Neg\ (I-E_{tp})$				-4.77		-2.88						-1.98	
S	0.80	0.80	0.80	0.00	0.80	0.00	0.80	0.80	0.80	0.80	0.80	0.00	0.80
ΔS	0.00	0.00	0.00	-0.80	0.80	-0.80	0.80	0.00	0.00	0.00	0.00	-0.80	0.80
E_{ta}	4.08	5.71	6.25	2.22	3.92	1.31	1.27	1.21	0.20	0.52	1.37	1.51	5.33
PERC	6.26	1.23	2.29	0.00	9.26	0.00	0.51	0.94	2.34	5.91	2.56	0.00	1.25

TABLE 5

SUMMARY OF PERCOLATION COMPUTATIONS FOR SURF CITY

Parameter	1984								1985				
	May	June	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May
E_{tp}	4.16	5.79	6.02	5.81	3.76	3.16	1.19	1.43	0.28	0.71	1.84	3.07	5.37
P	6.45	0.89	9.01	4.79	18.94	0.49	1.16	1.32	2.01	5.08	1.66	0.71	2.76
I	6.45	0.89	9.01	4.79	18.94	0.49	1.16	1.32	2.01	5.08	1.66	0.71	2.76
$I-E_{tp}$	2.29	-4.90	2.99	-1.02	15.18	-2.67	-0.03	-0.11	1.73	4.37	-0.18	-2.54	-2.61
$\Sigma Neg\ (I-E_{tp})$		-4.90		-1.02		-2.67	-2.70	-2.81			-0.18	-2.72	-5.33
S	0.80	0.00	0.80	0.00	0.80	0.00	0.00	0.00	0.80	0.80	0.62	0.00	0.00
ΔS	0.00	-0.80	0.80	-0.80	0.80	-0.80	0.00	0.00	0.80	0.00	-0.18	-0.62	0.00
E_{ta}	4.16	1.69	6.02	5.59	3.76	1.29	1.16	1.32	0.28	0.71	1.84	1.33	2.76
PERC	2.29	0.00	2.19	0.00	14.38	0.00	0.00	0.00	0.93	4.37	0.00	0.00	0.00

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